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# THE ASTROPHYSICAL JOURNAL

## An International Review of Spectroscopy and Astronomical Physics

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# JULIUS SCHEINER

By EDWIN B. FROST

After a long and painful illness, which had greatly restricted his scientific activity for many months, Julius Scheiner, a senior observer at the Royal Astrophysical Observatory at Potsdam, and extraordinary professor of astrophysics at the University of Berlin, died on December 20, 1913, at Potsdam. He was born at Cologne on November 25, 1858, the son of Jacob Scheiner, a painter of landscapes and architectural subjects of that city.

Julius Scheiner attended the elementary schools at Deutz, a suburb of Cologne, later entering the Realgymnasium in the city. His interest was early aroused in physics, partly by the genius of his teachers in that branch, to whom he acted as an assistant. Upon passing his *Abiturienten* examination in the spring of 1878, he entered the University of Bonn, devoting his attention chiefly to mathematics and natural science. He had as a schoolboy visited the famous observatory at Bonn, and the interest then developed soon led him to turn his attention to astronomy as a career. The traditions of the institution established by Argelander and then directed by Schönfeld doubtless had their full influence upon the young student. He was skilful in the use of instruments and after a couple of years at the

university took part in the observations of the observatory. He took his Doctor's degree in the spring of 1882, with a thesis which discussed the observations of Algol made by Schönfeld at Mannheim from 1869 to 1875. He had already received the appointment as assistant at the observatory and was assigned to the zone observations with which Dr. Deichmüller was engaged.

At this period came the year of military service, which, contrary to expectation, proved to be of benefit to the health of the young man, who already had some heart trouble. He thereafter returned to his work and made himself valuable as well as personally attractive to Schönfeld and an interesting circle of scientific men at Bonn. The emoluments of his position at the observatory were not such, however, that he could forsee the realization of his hopes of marriage (having been engaged for some years), and he looked for an opportunity for work in the recently established astrophysical observatory at Potsdam under the efficient direction of H. C. Vogel. It was not for a couple of years that a position could be offered him that promised a living and gave hope of future advancement, but, on January 1, 1887, the young Rheinländer entered the service of the astrophysical observatory where for a quarter of a century he was destined to find a full opportunity for the exercise of his marked talents as an investigator and writer. Vogel had been a student in Leipzig of Zöllner, the first German professor of astrophysics, and thus Scheiner's intellectual pedigree in astrophysics runs back to as appropriate a source as it had in Bonn for the older branch of astronomy.

The work in progress at Potsdam was at a very interesting phase: the work on the astrographic chart was just beginning, and many new problems, both instrumental and theoretical, had to be worked out. Vogel was also planning to apply the photographic process to the measurement of stellar velocities in the line of sight, his earlier work by the visual method having convinced him of the prohibitive difficulties of that mode of observation. As the health of Vogel did not permit him to take much part in the actual observations with the new instrument which he had designed and named the spectrograph, Scheiner had an unusual opportunity to collaborate with his chief, and his zeal and skill contributed much to the suc-

cessful outcome of the experiments of the new method. In 1888 and 1889 observations were secured of the 50 brighter stars with the spectrograph attached to the Schroeder refractor of 12 in. (300 mm) aperture. The plates were measured by both Vogel and Scheiner, and the final results were published in Part I of the seventh volume of the *Potsdam Publications* in 1892. Aside from their value for determinations of velocity the spectrograms contained a wealth of information as to their classification, the identification and character of the lines, and their intensities, and precise wave-lengths. This part of the work was assigned to Scheiner by Vogel and appears as the second part of the same volume.

At this time also there was much interest in the observations of the motion in the line of sight of Algol. In the winter of 1888–1889 it was apparent that before a minimum the bright star was moving away from the sun, and toward the sun after a minimum; and plates taken in the following season fully confirmed this, so that a preliminary communication could be made by Vogel and Scheiner to the Berlin Academy on November 28, 1889, of the orbit of the star with an indication of the size and mass of the components.

Scheiner's relations to Vogel became very confidential at this period, and his position corresponded somewhat to that of "assistant to the president" in some of our business corporations. Since Vogel's health could not well undergo the strain of the international conferences, Scheiner was deputed to represent the observatory at the meetings of the delegates of the Astrographic Chart in Paris in 1891, 1896, and 1900. He also attended the meeting in 1909. He also relieved the director of much of the labor of preparing annual reports and generally attended to the numerous scientific visitors who came to Potsdam to learn the methods being introduced in the active institution which was the unquestioned leader in astrophysical work.

Scheiner fully appreciated the eminent services and abilty of Vogel in astrophysics, and Scheiner's work and writings reflected in a marked degree the views of his chief. Scheiner inherited from his father skill in drawing, and shortly after his arrival at Potsdam prepared a valuable set of colored charts exhibiting

Vogel's classification of stellar spectra, and spectra of planets, comets, and nebulae, which were published by a Vienna firm.

Meanwhile Scheiner was also occupied with a work on celestial spectroscopy which the firm of Engelmann of Leipzig (of which one member had been an astronomer) had long desired Vogel to undertake, but which he felt it necessary to decline. The book was *Die Spectralanalyse der Gestirne*, published in the latter part of 1890, with the indorsement of a preface by Vogel, whose views it fully represented. It was received with marked approval by those already interested in celestial spectroscopy and attracted the attention of many others to this branch of astrophysics. It brought to Scheiner considerable reputation as an authority in this field of science. A revised edition in English appeared about four years later and had a considerable sale.

As has been stated, Scheiner was also much occupied in the early nineties with celestial photography and preparations for the astrographic chart. Among the problems was that of reproducing the *reseaux* to be imprinted on the negatives. A method of doing this was worked out by Scheiner and then employed by the French and German instrument-makers. The question of permanency of the sensitive film and of the effect of length of exposure upon the accuracy of the positions were also studied. He investigated the law of the increase of the size of the image with increasing exposure; he also devised a sector sensitometer for testing the speed of plates. He tested the validity of the supposed law of photographic photometry, $it$ = constant, upon which the conference of the Carte du Ciel had based some of its resolutions in 1889, and showed that it was incorrect,[1] and that a two-and-a-half fold increase of exposure caused a gain of nearer half a magnitude than a whole magnitude. He also proposed a simple photographic method for correcting the errors of adjustment of equatorial telescopes.

It should be mentioned that Scheiner was one of the first clearly to recognize what we now call the color-index of a star. In *Astronomische Nachrichten* (**124**, 273, 1890) he published the results of an investigation, "Ueber die Bestimmung von Sterngrössen aus photographischen Aufnahmen," in which he says: "As a result of

[1] He seemed to be unaware that Pickering had previously proved the same thing.

the comparison we may conclude that the differences between photographic and visual magnitudes lie between 1.5 and 2.0 magnitudes for the second spectral type, and certainly exceed 2.5 magnitudes for spectral class IIIa."

The Potsdam photographic refractor having the optical dimensions of the astrographic standard, but with important modifications of the mounting by Repsold to meet the requirements of Vogel, had been set up in 1889, and Dr. Scheiner was occupied with numerous experimental exposures with it. One of the results of this was the measurement (1891) of two negatives of the great cluster in Hercules, Messier 13, from which the positions of 823 stars were determined and the relative magnitudes inferred. The operations are familiar enough nowadays, but it was a new field at that time, and many points had to be worked out from the beginning. It was the writer's great privilege to be associated with Dr. Scheiner in some of this work in 1891 and 1892, and thus to learn to admire the insight and skill of Scheiner at the telescope, in the dark room, and at the measuring machine. In 1894 Scheiner undertook a triangulation of the principal stars (374 in number) and definable points in the Orion nebula, 128 in all, on several photographs taken with the astrographic refractor and with a Voigtländer euryscope. This should serve as a basis for future studies of motions of the nebula and the stars near it. When the routine work of the astrographic chart was begun the duty of its immediate supervision fell to Scheiner, and six large volumes have appeared under his care (I, 1899; VI, 1912), containing the rectangular co-ordinates and approximate places for 1900 of 123,712 stars of the zone from $+31^\circ$ to $+40^\circ$ of declination. The measures of revision and checks were made by Scheiner in many cases, and the scheme of measurement and reduction, described at length in the introduction to the first volume, of course devolved upon him.

The success of *Die Spectralanalyse der Gestirne* led him to undertake the companion volume, *Die Photographie der Gestirne*, which appeared in 1897. It was accompanied by a handsome atlas in heliogravure intended to represent the achievements of celestial photography up to that date. The author's aim, as stated in the preface, was to contribute all in his power to develop celestial

photography into a rigorous and exact science. G. Müller's admirable *Photometrie der Gestirne* completed the series of three works on astrophysics, but in 1899 Scheiner contributed through the same publisher, in a volume of a hundred pages, a monograph entitled *Strahlung und Temperatur der Sonne*. In 1902 Scheiner made observations on the solar constant and temperature of the sun with an Ångström pyrheliometer at the Gorner Grat in Switzerland and at Potsdam, the results of which were published in the eighteenth volume of the *Potsdam Publications*.

After the successful introduction of the spectrographic method of measuring radial velocity of the stars, it was most natural that Vogel should wish to continue that work with a large refractor. His efforts at length obtained the support of the Prussian government, and Scheiner and his colleague Wilsing were occupied in aiding the director in the plans for the new instrument. It was inaugurated with elaborate ceremonies, in the presence of Emperor William, in 1899, and to Scheiner was assigned the part of explaining to the audience some of the details of the great refractor (of 80 cm aperture, with a visual guiding telescope of 50 cm aperture) and of the dome. The high expectations for this splendid instrument, by far the largest in the empire, most unfortunately were not realized, owing to its optical imperfections.[1] The detection of the causes of these defects caused much labor and worry to the director and to the observers assigned to the tests, Messrs. Scheiner, Wilsing, and Hartmann. Unfortunate differences of opinion arose which impaired the close relations between Scheiner and his director, and thereafter executive duties were not often assigned to him. His work with the great telescope was henceforth done in collaboration with his colleague Professor J. Wilsing, with whom his relations were always close.[2] The first investigation, made at the suggestion of Vogel, was a photometric determination of the relative intensities of the three principal lines in the nebular

[1] Successive refiguring has much improved the 80 cm lens, and at this writing we understand that a final retouching has been completed which we may hope will bring it to a satisfactory degree of excellence.

[2] The writer is indebted to Professor Wilsing for a manuscript sketch of the life of his friend Scheiner, upon which much of the present sketch is based.

spectrum. The radial velocities of nine of the brighter gaseous nebulae were next measured visually, the dispersion being supplied by a grating. The results were in good accordance with those made by Keeler visually with the Lick refractor and with some other photographic determinations.

The next important piece of work, and one involving much observational skill, was also done in collaboration with Professor Wilsing and occupies 221 pages of the nineteenth volume of the *Potsdam Publications*, under the title "Temperaturbestimmung von 109 helleren Sternen aus spektralphotometrischen Beobachtungen," 1909. Little or no work had been done in this direction visually since observations were made by Vogel and Müller on a few of the brightest stars about thirty years before. Meanwhile much experimental and theoretical research had been devoted to the black body and the laws of radiation, so that indications could be given of the effective temperature of over 100 stars, many of them as faint as the fourth visual magnitude. To the writer it would seem that the full significance of this important research had not yet been properly appreciated by astronomers, still less by writers of textbooks. It is of the greatest importance to establish that the relation of spectral type and temperature follows the sequence of Vogel's classification, as shown in this extract:

| Type | No. of Stars | Temperature ($c=14{,}200$) |
|---|---|---|
| Ib | 8 | 11,500° |
| Ia1 | 4 | 11,600 |
| Ia2 | 22 | 10,300 |
| Ia3–IIa | 16 | 7,100 |
| IIa | 7 | 5,900 |
| IIa–IIIa | 41 | 4,200 |
| IIIb | 7 | 3,300 |

Even if the values of the absolute temperature may be subject to a considerable uncertainty, the determination of the relative value is of the highest importance in any theory of stellar evolution. These results of Wilsing and Scheiner (the former did the work of deriving the temperature from their joint observations) have been

confirmed, relatively, by other investigators, whose determinations would seem, however, to be of far less reliability.

The twentieth volume of *Potsdam Publications* (1909) contains another spectral-photometric research by Wilsing and Scheiner, made in part with the large refractor, entitled "Vergleichende spektralphotometrische Beobachtungen am Monde und an Gesteinen nebst Albedobestimmungen an Letzteren."

In the same volume Scheiner published a catalogue of 1564 double stars found in the first four volumes of the *Potsdam Astrographic Catalogue*, with a statistical study of their relative frequency.

In spite of continuous occupation with research Scheiner still found time for more popular writing and for lectures as extraordinarius at Berlin, where his appointment dated from 1894. In 1908 Teubner published Scheiner's *Populäre Astrophysik*, a fully illustrated work of 718 pages, expanded from his Berlin courses on celestial spectroscopy, photometry, and photography. A second edition appeared in 1912. The style is direct, clear, and holds the reader's attention. In a marked degree Scheiner possessed the art of popularizing, and writing seemed very easy to him.

In 1909 appeared in Barth's series known as "Wissen und Konen" a small volume of 187 pages by Scheiner, entitled *Spektralanalytische und photometrische Theorien*. While not popular (it is printed in the Latin instead of the German type, which is the most obvious distinction in Germany between a scientific and a popular presentation of truth), this work was intended for those interested in astrophysics but not specialists in that branch. It serves a useful purpose.

Scheiner wrote frequently for the semipopular magazines and journals, and he contributed to Teubner's series "Aus Natur und Geisteswelt" a small volume entitled *Der Bau des Weltalls* (1900), of which the fourth edition appeared in 1913. He gave public lectures occasionally, once going by invitation to Lyons for the purpose. His achievements were rewarded by certain of the orders or decorations which are highly regarded by the subjects of monarchical forms of government. He was elected an associate of the Royal Astronomical Society in 1901.

Aside from his capacity as a teacher, Scheiner's most marked ability was on the experimental side of research. He was ingenious with apparatus and could quickly devise an experiment for settling a debated point. After it was settled to his own satisfaction, sometimes perhaps on inadequate data, he was persistent in upholding his view, and this led him into occasional controversies, in which he was sometimes in the wrong. But his faculty of interpretation of nature by experiment must be recognized as unusual; the writer would characterize it as insight.

Scheiner was a jovial companion, a capital story-teller, and enjoyed social gatherings with his colleagues and friends. His home life represented the typical German *Familienglück*. He was married in 1888, and in the first years lived in a modest way in one of the observatory houses on the Telegraphenberg. His wife devoted herself to the interests of her husband and their three daughters and during the illness of his last years he thus received the most constant and affectionate attention. He had always been subject to a nervous affection of the heart and as he had early grown too stout for his best health, it became somewhat difficult for him to take the exercise that was good for him. His eyesight was affected a few years ago so that work at the telescope had to be given up. It was a great satisfaction to the writer to find him in the spring in 1913 in better health than he had been for some time past, so that memories of earlier days could be pleasantly recalled. The apparent improvement continued after his annual visit to the Baltic seashore, and he essayed to resume his work at the observatory in the autumn, but a stroke of apoplexy suddenly ended his life at the far too early age of fifty-five years.

# COMPARISON BETWEEN THE DISTRIBUTION OF ENERGY IN THE SPECTRUM OF THE INTEGRATED LIGHT OF THE GLOBULAR CLUSTER MESSIER 3 AND OF NEIGHBORING STARS

By E. HERTZSPRUNG

A spectrum of the integrated light of Messier 3 = N.G.C. 5272 ($13^h37^m.5$, $+28°23'$; 1900) was obtained with the UV Zeiss triplet of the Potsdam observatory ($a = 15$, $f = 150$ cm) in connection with an objective prism of $7°.5$ deviation, giving a dispersion of 1 mm to 137 A at $H_\gamma$. The exposure on the region of Messier 3 was made February 2, 1914, from $12^h.0$ to $14^h.3$ sidereal time Potsdam, on a Hauff Ultra-rapid plate, under good atmospheric conditions.

The dispersion used is not sufficient to show any lines in the integrated spectrum of the globular cluster. To fix the wave-lengths, therefore, an additional plate was taken without the prism, in order to determine the position of the cluster relative to the stars. It was found in this way that the lines in the spectrum of the star B.D.+28°2251 must be shifted 4.55 mm to the north to coincide with the invisible lines in the spectrum of the cluster.

The spectra of the stars were made 0.29 mm broad by changing the run of the clock and turning back with the slow motion every few minutes. The plate was measured in the Hartmann micro-photometer. The small field screened out on the plate by the Lummer-Brodhun prism was of circular shape with a diameter of 0.14 mm. Instead of several settings being made at some few selected wave-lengths, the spectrum was measured throughout in steps of 0.1 mm.

To eliminate the difference between the continuous spectrum of the cluster and the spectra of the stars with sharp absorption lines, the measures of the latter were smoothed graphically to such an extent as to give the spectrum of a cluster consisting only of identical stars. The shape and size of the globular cluster

Messier 3 is roughly equivalent to a uniform circular disk of 40″ or 0.3 mm in diameter.

It was necessary to reduce the scale-readings of the microphotometer to the magnitude scale. This purpose was served by a plate of the north polar region taken on the same night from $9^h.4$ to $10^h.7$ sidereal time through the objective grating and 3 mm intrafocal, as described in *A.N.*, 4452. A Hauff plate from the same box as for the cluster spectrum was used. The two plates, of the cluster and of the north polar region, were developed together in the same tank and the fog after development therefore proved to be the same in both. On the north polar plate both the central image and the spectra of first order—being different by 0.95 mag.—were measured in the microphotometer for 37 stars. The relation obtained in this way between microphotometer reading and differential stellar magnitude was used for the cluster plate. As will be seen below, the spectral intensities of the cluster are fairly near the same as of the stars B.D.+28°2259 and +27°2288. To find the differences in the distribution of energy in the spectra of the cluster and of these stars, therefore, only an approximate knowledge of the relation between microphotometer reading and stellar magnitude is needed. The determination of this relation by means of the north polar plate, as just described, is therefore sufficiently safe.

The results of the measures of the spectra of Messier 3 and of five selected stars in the neighborhood are given in Table I. The first column gives the distance in millimeters from the K line, the second the corresponding wave-length. The third column gives the magnitude equivalent of the density in the photograph of the spectrum of Messier 3, counted from an arbitrary zero point. The following columns give the corresponding figures for the five selected stars and their differences from those of Messier 3. When this difference is constant for all wave-lengths, it means that the spectral distribution of energy is the same in the cluster and in the star.

For reference, the graphical representation of the measures of the cluster and of the star B.D.+27°2288 are shown in the accompanying figure. On each of the two diagrams are the scale

TABLE I

| Distance from K Line | Wave-Length A | Messier 3 | +27°2288 F3 | +28°2259 A4 | +28°2254 F1 | +28°2251* F1 | +28°2248 K1 |
|---|---|---|---|---|---|---|---|
| mm | | | | | | | |
| −8.0 | 5153 | ..... | ..... | ..... | 4m57 ..... | ..... | 3m78 ..... |
| −7.5 | 5035 | 4m26 | 4m44 −0m18 | ..... | 4.12 +0m14 | ..... | 3.35 +0m91 |
| −7.0 | 4925 | 3.41 | 3.85 − .44 | 4m10 −0m69 | 3.05 + .36 | 4m39 −0m98 | 2.29 +1.12 |
| −6.5 | 4823 | 2.77 | 2.93 − .16 | 3.21 − .44 | 2.17 + .60 | 3.46 − .69 | 1.54 +1.23 |
| −6.0 | 4728 | 2.38 | 2.37 + .01 | 2.56 − .18 | 1.56 + .82 | 2.84 − .46 | 1.13 +1.25 |
| −5.5 | 4638 | 2.18 | 2.10 + .08 | 2.34 − .16 | 1.23 + .95 | 2.53 − .35 | 0.96 +1.22 |
| −5.0 | 4555 | 2.09 | 2.00 + .09 | 2.18 − .09 | 1.13 +0.96 | 2.43 − .34 | 0.95 +1.14 |
| −4.5 | 4476 | 2.11 | 2.00 + .11 | 2.13 − .02 | 1.08 +1.03 | 2.40 − .29 | 1.05 +1.06 |
| −4.0 | 4402 | 2.16 | 2.05 + .11 | 2.13 + .03 | 1.08 +1.08 | 2.42 − .26 | 1.22 +0.94 |
| −3.5 | 4331 | 2.23 | 2.10 + .13 | 2.16 + .07 | 1.10 +1.13 | 2.47 − .24 | 1.47 + .76 |
| −3.0 | 4265 | 2.29 | 2.16 + .13 | 2.21 + .08 | 1.12 +1.17 | 2.49 − .20 | 1.70 + .59 |
| −2.5 | 4203 | 2.34 | 2.19 + .15 | 2.27 + .07 | 1.16 +1.18 | 2.54 − .20 | 1.88 + .46 |
| −2.0 | 4143 | 2.42 | 2.22 + .20 | 2.35 + .07 | 1.21 +1.21 | 2.61 − .19 | 1.98 + .44 |
| −1.5 | 4087 | 2.47 | 2.36 + .11 | 2.42 + .05 | 1.29 +1.18 | 2.68 − .21 | 2.03 + .44 |
| −1.0 | 4033 | 2.59 | 2.47 + .12 | 2.50 + .09 | 1.37 +1.22 | 2.75 − .16 | 2.14 + .45 |
| −0.5 | 3982 | 2.78 | 2.61 + .17 | 2.61 + .17 | 1.55 +1.23 | 2.85 − .07 | 2.53 + .25 |
| 0.0 | 3934 | 2.96 | 2.78 + .18 | 2.75 + .21 | 1.70 +1.26 | 3.00 −0.04 | 3.16 − .20 |
| 0.5 | 3888 | 3.13 | 2.98 + .15 | 2.94 + .19 | 1.92 +1.21 | ..... | 3.62 − .49 |
| 1.0 | 3843 | 3.33 | 3.20 + .13 | 3.18 + .15 | 2.16 +1.17 | ..... | 4.16 − .83 |
| 1.5 | 3801 | 3.48 | 3.39 + .09 | 3.46 + .02 | 2.37 +1.11 | ..... | 4.08 − .60 |
| 2.0 | 3761 | 3.69 | 3.55 + .14 | 3.72 − .03 | 2.68 +1.01 | ..... | 3.91 − .22 |
| 2.5 | 3722 | 3.89 | 3.68 + .21 | 3.91 − .02 | 2.98 +0.91 | ..... | 4.25 − .36 |
| 3.0 | 3685 | 4.08 | 3.80 + .28 | 4.12 − .04 | 3.29 + .79 | ..... | 4.01 + .07 |
| 3.5 | 3649 | 4.31 | 3.98 + .33 | 4.31 .00 | 3.54 + .77 | ..... | 4.16 + .15 |
| 4.0 | 3615 | 4.56 | 4.11 +0.45 | 4.44 +0.12 | 3.86 +0.70 | ..... | 4.42 +0.14 |
| 4.5 | 3582 | ..... | 4.31 ..... | ..... | 4.15 ..... | ..... | ..... |
| 5.0 | 3550 | ..... | 4.47 ..... | ..... | 4.50 ..... | ..... | ..... |
| 5.5 | 3520 | ..... | ..... | ..... | ..... | ..... | ..... |
| 6.0 | 3491 | ..... | ..... | ..... | ..... | ..... | ..... |

*The shorter wave-lengths of +28°2251 interfere with the spectrum of +29°2452.

of wave-lengths indicated below, of magnitude corresponding to the density on the photograph to the left, of distances from the K line above, and of microphotometer readings to the right. The graphical smoothing of the measures of the star spectrum as described above will be seen in the figure. It may be noted that the UV Zeiss triplet has been so achromatized that the minimum focus lies about at the wave-length λ 3900, and light at λ 4800 is about 3 mm out of minimum focus. The great similarity in the spectral distribution of energy in the cluster and in the star B.D.+27°2288, in the region examined, is striking, especially

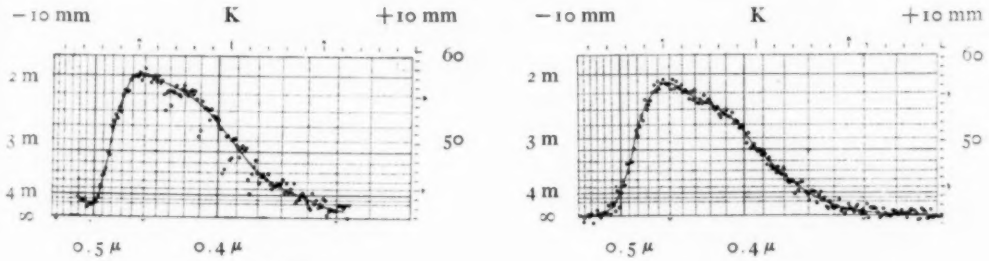



FIG. 1

between the wave-lengths λ 3761 (+2.0 mm from the K line) and λ 4555 (−5.0 mm), where the determination is best. At the longer wave-lengths the exactness may be affected by the quick change in the density of the spectrum and at the very shortest ones the density is so small that the measures become uncertain. There also the "head" of the hydrogen series may cause trouble. Light in the spectrum of the cluster is traced to about λ 3500.

The spectral types indicated in the table are derived from my estimates of the relative intensities of the K line and of the hydrogen lines. For the star +28°2248 the line λ 4227 was used.

Altogether it is seen that the distribution of energy in the integrated spectrum of Messier 3 between λ 3761 and λ 4555 is very nearly like that of a typical F star.

According to Mr. Fath (*Astrophysical Journal*, **33**, 62, 1911) the spectrum of Messier 3 lies between A and G. This agreement

between spectral lines and distribution of energy in the same part of the spectrum, where the lines for classification have been observed, does not indicate any sensible selective extinction of light in space.

Compared with the results of Mr. Babcock (footnote to J. C. Kapteyn, "Absorption of Light in Space," *Astrophysical Journal*, **30,** 316, 1909) on three other globular clusters, this conclusion is somewhat unexpected. I was therefore eager to get also visual comparisons of the integrated light of Messier 3 with some of the comparison stars used above. This has been accomplished in two ways. First I measured (June 29, 1914) with a small visual refractor ($a=13$, $f=210$ cm) how far I had to go out of focus to get the extrafocal disk of the cluster or of the comparison star of a certain estimated brightness in contrast to the background of the sky. This gave me: magnitude of Messier 3 minus magnitude of B.D.+28°2254 equal to +0.31 mag. (or the magnitude of Messier 3 is 7.06 mag.+0.31 mag.=7.37 mag. on the Harvard scale). Then, this result being somewhat uncertain, Professor Müller had the kindness to measure (June 30, 1914) the total brightness of the cluster with the short-focus photometers C1 and C2 (*Publ. Potsdam*, **17,** p. vii). The difference in magnitude against the star B.D.+28°2254 was found to be +0.34 mag. (or the magnitude of the cluster on the Potsdam scale is 7.28 mag.+0.34 mag.=7.62 mag.).

Assuming the visual measures to correspond with a wave-length of 5600 A, we then have the brightness of Messier 3 at different wave-lengths relative to certain stars as shown in Table II.

TABLE II

| Wave-Length | Star | +27°2288 | +28°2259 | +28°2254 | +28°2248 |
|---|---|---|---|---|---|
| | Spectrum | F3 | A4 | F1 | K1 |
| | Vis. Mag. Harvard | — | — | 7.06 | 6.36 |
| | Vis. Mag. Potsdam | 8.24 | 8.25 | 7.28 | 6.37 |
| λ 3761 | | +0.14 mag. | −0.03 mag. | +1.01 mag. | −0.22 mag. |
| 4555 | | +0.09 | −0.09 | +0.96 | +1.14 |
| 5600 | | −0.63 | −0.64 | +0.33 | +1.13 |

Hence Messier 3 is about 0.6 mag. brighter visually than a star showing the same spectral intensities as the cluster at λ 3761

and λ 4555. This difference may be due to a possible composite character of the integrated spectrum of the cluster. In fact for another cluster, Messier 13, Mr. Pease (*Carnegie Inst. Year Book*, 1913) found among 19 stars all steps between A and G. At any rate, in questions bearing on selective extinction of light in space the spectral class on one side and the distribution of energy on the other should at least be derived from an examination of the same region of the spectrum.

In addition to the foregoing it may be noted that the integrated light of the globular cluster Messier 15=N.G.C. 7078 is well measurable on the plates of the *Göttingen Actinometry*, in the scale of which I found its photographic magnitude to be 7.87 mag. The visual Harvard magnitude is 7.26 mag. (*Harv. Ann.*, **14**) and Professor Müller found the difference against the star B.D.+ 11°4573 to be −0.06 mag., hence the visual Potsdam magnitude of the cluster is 7.44−0.06=7.38 mag.

The color-index we find from the Harvard measure to be mag. phot., Gött.−mag. vis. Harv.=+0.61 mag. and from the measure of Professor Müller 0.77×0.49+0.27+0.04×0.88=+ 0.68 mag. (*Gött. Act.*, B, **25,** formula 2). This color-index corresponds to a star with spectrum G 4.

Concerning the integrated spectrum of Messier 15, Mr. Fath (*Lick Bull.*, **5,** 74, 1909) concludes that stars of the F type are predominant. The color-index corresponding to a star of this type averages +0.32 mag. Hence Messier 15 is about 0.34 mag. brighter visually than an F star of the same photographic magnitude. This agrees well enough with the corresponding result found above for Messier 3.

POTSDAM
July 30, 1914

# OBSERVATIONS OF THE *GRUNDSPECTRA* OF ALKALI AND ALKALINE EARTH METALS

By EDGAR H. NELTHORPE

## INTRODUCTORY

In 1908[1] Goldstein described a method by which he obtained line spectra of potassium, rubidium, and caesium which were totally different from the arc spectra of these elements and could not be arranged in series of the ordinary type. The new spectra were called *Grundspectra*, but, as Goldstein pointed out, some of the lines had previously been observed to occur in spark spectra in company with the ordinary series lines. In fact, all the new lines given for potassium by Goldstein have since been recorded in the potassium spark by Schillinger,[2] who used a spark between metallic potassium electrodes in an atmosphere of hydrogen. Goldstein's method therefore appeared in some cases to result in the complete isolation of the enhanced (spark) lines from the arc lines occurring in the ordinary arc or spark. In view of the fact that enhanced lines appear without the arc lines in the spectra of some of the stars, it seemed desirable to repeat Goldstein's observations of the metals of the alkali group, and, if possible, to extend them to some of the elements which are represented in stellar spectra. The elements studied during the present investigation were sodium, potassium, rubidium, calcium, strontium, and barium.

## APPARATUS EMPLOYED

Goldstein's first types of apparatus[3] were such that the anode in an evacuated tube was completely covered with the solid salt, and the discharge followed a path between the salt and the walls of the tube. In this method, however, the light is not of such a nature that it can easily be examined with a spectrograph: first,

[1] *Astrophysical Journal*, **27**, 25, 1908.

[2] *Wien. Ber.*, **118**, II(*a*), 1909.

[3] *Verh. der deutsch. phys. Gesell.*, **12**, 426, 1910.

because it is not of a great enough intensity, and second, and more important, because the walls of the tube in most cases get covered very quickly with a thick deposit of a darkish color. Hence, the form of discharge tube adopted in the present investigation was somewhat after the fashion of Goldstein's later types; that is to say, an H-shape.

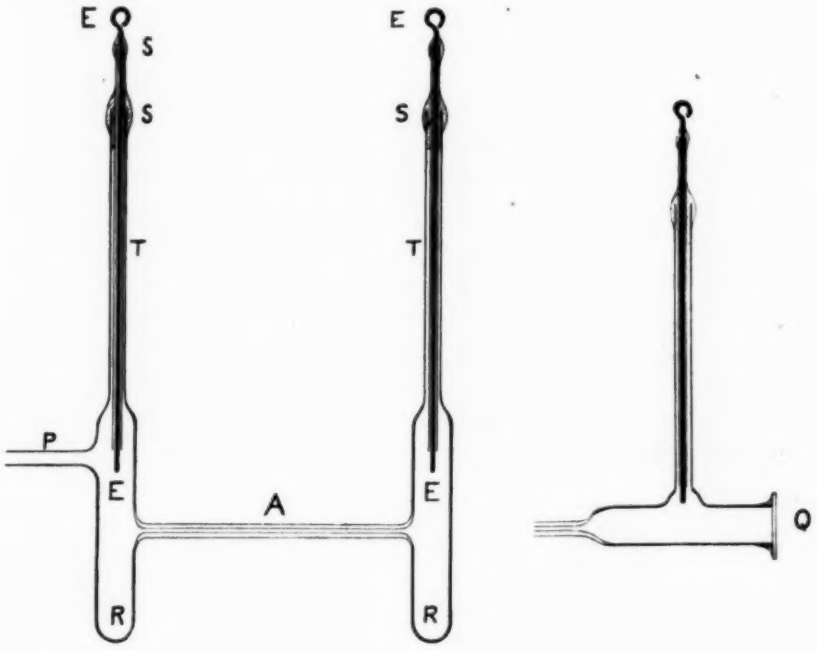



FIG. 1

The side tubes (*R*) were about 1.5 cm in diameter and were connected by a horizontal capillary tube (*A*) of 1 mm bore. Aluminium electrodes (*E*) were carried through the narrow connecting tubes (*T*) to which they were attached in the usual way with air-tight joints of sealing-wax (*S*). A small quantity of the powdered salt was placed at the bottom of each of the side tubes and could then be run into the capillary by a suitable manipulation of the tube. The end-on view of the tube is preferable, owing to the greater intensity of light obtained, and the spectrum may then be photographed down to about λ 3100; but if the broadside view

is taken, as is sometimes necessary, the spectrum does not reach beyond about λ 3400, on account of the greater thickness of the capillary tube as compared with the bulb. For wave-lengths still farther in the ultra-violet the tube may easily be modified to include a quartz window (*Q*). In all cases the tube was joined at *P* to a tube containing phosphorus pentoxide, and put into connection with a charcoal bulb, which could be cooled by liquid air, for the production of a high vacuum when desired. The drying tube is very necessary in the case of deliquescent salts, as when the substance is wet one obtains the spark spectrum of oxygen and hydrogen instead of that of the metal or halogen.

An induction coil giving at least a 10-inch spark would appear to be necessary. The condenser was joined across the secondary, and the tube and an air-gap were in series with one another but in parallel with the condenser. In most cases it was found necessary to use a larger coil giving a 12-inch spark, the primary taking anything up to about 10 amperes. With this coil a motor mercury-break was used. Under some conditions a small capacity and long air-gap were found to work best, while a large capacity and short air-gap gave better results in other cases.

### POTASSIUM

The first substance investigated was potassium chloride. The solid salt in the bulb phosphoresces a beautiful violet, probably under the influence of cathode rays, and that in the capillary changes to a bluish-green color which may remain for weeks. With a sufficiently low pressure and a highly condensed discharge the capillary tube glows with a brilliant green light and in this case may be viewed end-on with advantage. The green coloration is due to the liberation of chlorine, and a preliminary examination of the spectrum might suggest that it was that of chlorine alone, as concluded by Goldstein.[1]

A closer examination, however, shows the presence of a number of other lines, some of which agree in position with lines given by Goldstein for potassium when the fluoride was used.

[1] Goldstein states that a condensed discharge with chlorides gives the chlorine spectrum alone, but with fluorides the *Grundspectrum* of the metal is obtained, the spectrum of fluorine being weak.

Most of the chlorine lines were easily identified, but some of those tabulated by Eder and Valenta seemed to be entirely absent, while a few others were greatly intensified.

Potassium bromide shows even more brilliance than the chloride when the discharge is passed, and the spectrum obtained is still more complicated, owing to the large number of lines in the bromine spectrum. By joining the two tubes together, the spectra of the chloride and bromide under the same experimental conditions were obtained as comparisons, and many of the potassium lines were thus easily distinguished.

The fluoride of potassium was found to be much more difficult to work with. In the first place, it must be carefully dried before use or one obtains nothing but lines of hydrogen and oxygen. Then, again, the end-on view was not permissible, as it always showed impurities such as air and carbon lines, and these usually predominated in the spectrum. The broadside view gave a purer spectrum, but the impurity lines were still present except in the near neighborhood of the most closely packed salt in the tube. A further difficulty was caused by the walls of the tube getting coated long before a reasonable exposure could be given. Nevertheless, many of the strongest potassium lines were recognized in the photographs taken.

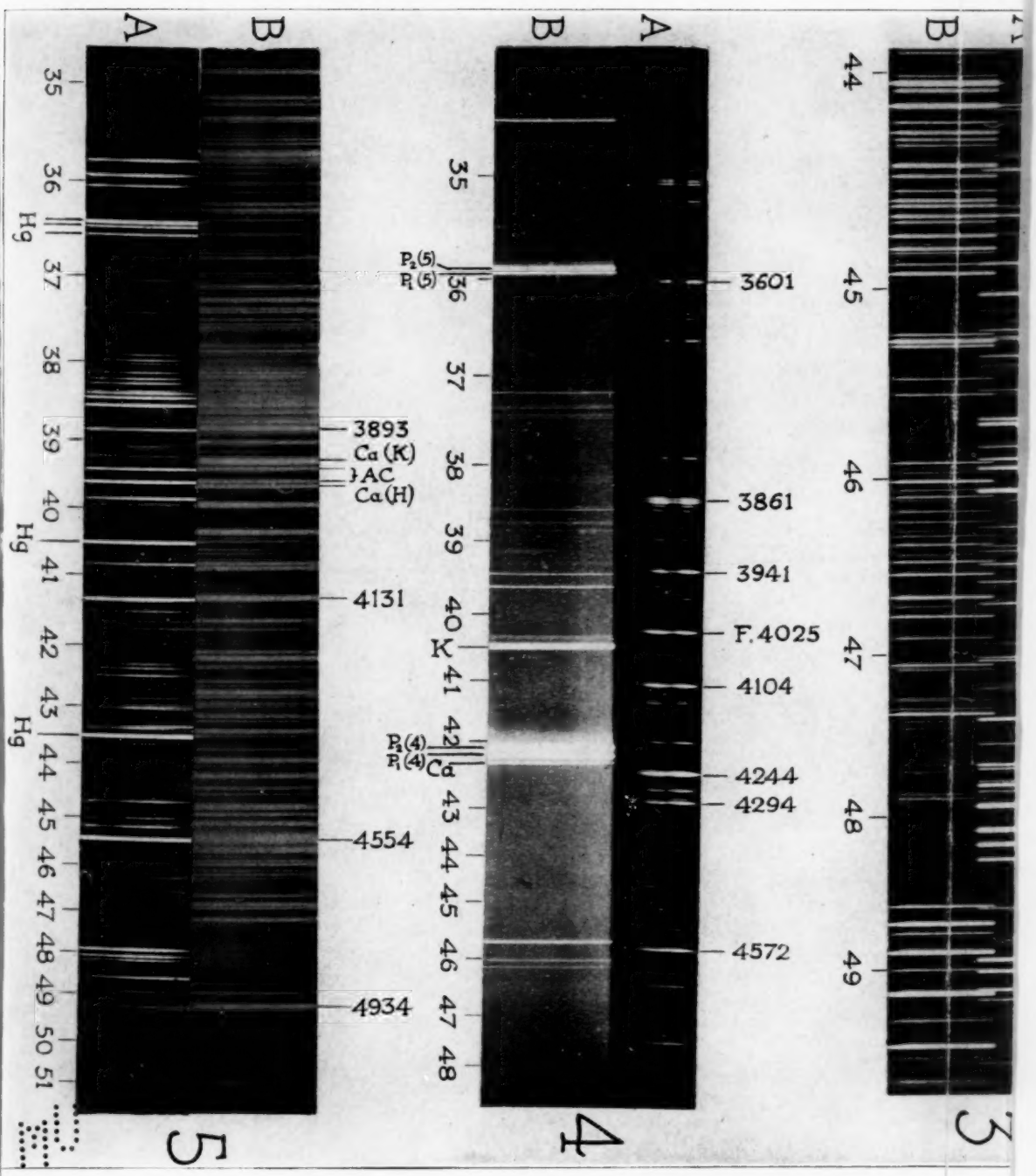
The plates obtained for the chloride were the best for the measurement of the potassium lines, as in the spectrum of the bromide many bromine lines fall in practically the same places as potassium lines, which therefore cannot be identified with certainty. A few of the stronger chlorine lines also usually occurred in the bromide spectrum, the chloride probably being an impurity.

Table I gives the wave-lengths of the stronger lines of the *Grundspectrum* of potassium down to λ 3900 as obtained from photographs taken with a single glass prism instrument mounted in the Littrow form. Goldstein's roughly approximate wave-lengths are indicated in the table, and Schillinger's wave-lengths for the potassium spark lines, with their intensities, are also given for comparison with those of the *Grundspectrum*. The entire absence of the principal series doublet at λ 4047 and λ 4044 from the *Grundspectrum* is very noticeable. In addition there were

## TABLE I

### POTASSIUM

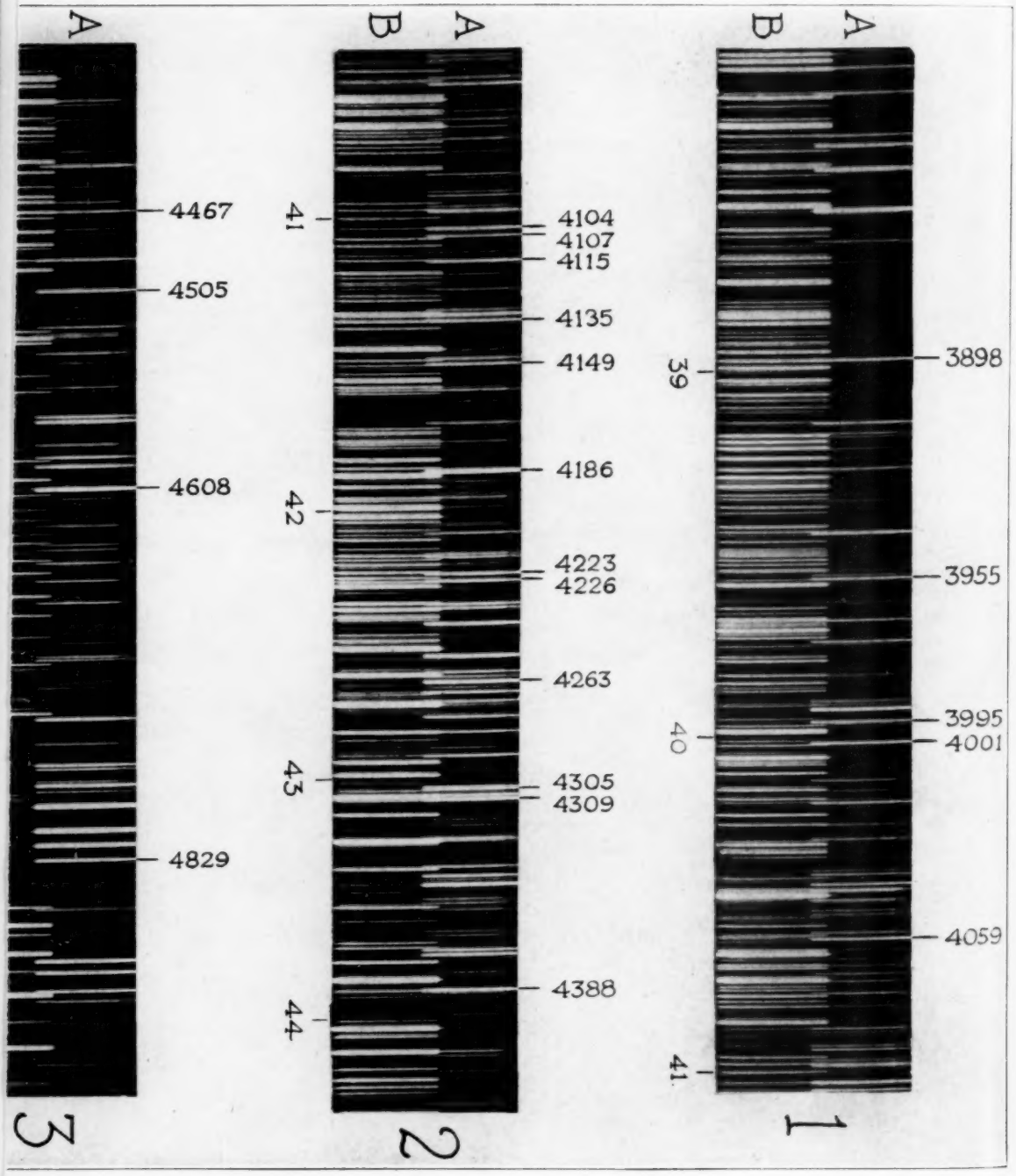
| *Grundspectrum* | | | SPARK | |
|---|---|---|---|---|
| NELTHORPE | | GOLDSTEIN | SCHILLINGER | |
| λ(I.A.) | Intensity | λ | λ(Rowland) | Intensity |
| 6307 | 3 | 630 | 6307.23 | 2 |
| 6247 | 1 | 624.5 | 6246.50 | 1 |
| 6120 | 8 | 611 | 6120.16 | 2 |
| | | | Subord. series | lines |
| 5005.5 | 5 | 501 | 5005.52 | 2 |
| 4829.0 | 12 | 483 | 4829.17 | 2 |
| | | | 4659.76 | 1 |
| 4607.7 | 15 | 461 | 4608.49 | 4 |
| 4505.3 | 8 | 451 | 4505.56 | 4 |
| 4466.6 | 5 | 447 | 4466.83 | 2 |
| 4423.7 | 1 | | 4423.89 | 1 |
| 4388.2 | 10 | 439 | 4388.30 | 1 |
| 4339.9 | 5 | | 4340.02 | 1 |
| 4309.1* | (?) | 431 | 4309.24 | 5 |
| 4304.9 | 4 | | 4305.17 | 3 |
| | | | 4288.64 | 1 |
| 4263.2 | 10 | 526 | 4263.48 | 8 |
| 4225.6 | 6 | 422 | 4225.76 | 4 |
| 4222.9 | 8 | | 4223.15 | 5 |
| | | | 4210.37 | 1 |
| 4186.1 | 20 | 418 | 4186.39 | 10 |
| 4149.2 | 10 | 415 | 4149.39 | 5 |
| 4134.7 | 10 | 413 | 4134.87 | 5 |
| 4115.0 | 10 | 411 | 4115.11 | 3 |
| 4106.8 | 5 | | | |
| 4104.2 | 7 | | | |
| 4098.6 | 3n | | | |
| 4093.8 | 2 | | 4094.53 | 1 |
| 4086.8 | 2 | | | |
| 4075.6 | 3 | | | |
| 4072.3 | 2 | | | |
| 4069.3 | 1n | | | |
| | | | 4066.64 | 1 |
| 4059.0 | 7 | | | |
| | | | 4048.10 | 2 |
| | | | 4047.35† | 10 |
| | | | 4044.31† | 20 |
| 4042.6 | 5 | | 4042.81 | 2 |
| | | | 4039.92 | 1 |
| | | | 4025.35 | 1 |
| 4018.5 | 4 | | 4018.26 | 1 |
| 4011.9 | 1 | | 4012.22 | 1 |
| 4001.3 | 8 | | 4001.35 | 5 |
| 3995.0 | 3n | | 3995.23 | 4 |
| 3972.5 | 4 | | 3972.36 | 3 |




1, 2, 3. The spectrum of potassium chloride, with iron are marked. Case in which the end-on view is taken. A:

4. The spectrum of rubidium fluoride, showing practic comparison. Case in which the broadside view is taken. A

5. The spectrum of barium chloride fused into alu A: barium chloride, *Grundspectrum;* B: barium arc.




ith iron arc comparison. The chief potassium spark lines
n. A: potassium chloride, *Grundspectrum;* B: iron arc.
practically only rubidium spark lines, with rubidium arc
ken. A: rubidium, *Grundspectrum;* B: rubidium arc.
nto aluminium electrode, with barium arc comparison.

TABLE I—*Continued*

| *Grundspectrum* | | | Spark | |
|---|---|---|---|---|
| Nelthorpe | | Goldstein | Schillinger | |
| λ(I.A.) | Intensity | λ | λ(Rowland) | Intensity |
| 3966.7 | 3 | | 3966.90 | 3 |
| 3955.2 | 8 | | 3955.42 | 7 |
| 3942.9 | 4n | | 3943.01 | 1 |
| 3934.5 | 1 | | 3934.60 | 1 |
| 3926.8 | 2 | | 3927.02 | 1 |
| | | | 3923.80 | 1 |
| 3897.9 | 10 | | 3898.01 | 8 |

* The line at λ 4309 falls in the same place as a chlorine line which is stronger in potassium chloride than in the chlorides of other metals and is therefore in part due to potassium.

† Arc doublet—$P_1(4)$ and $P_2(4)$.

a large number of both weak and strong lines in the ultra-violet which are not included in the table. Attempts to arrange the spark lines in series have, so far, been unsuccessful.

It will be observed that there is a very close accordance with Goldstein's observations in the region common to the two investigations, and that all but a few of the weakest lines of Schillinger's list appear in the *Grundspectrum*. A few lines which are not recorded by Schillinger in the potassium spark may possibly be enhanced lines of chlorine, which do not appear at all in the uncondensed discharge through chlorine in a vacuum tube.

### RUBIDIUM

The only rubidium salt experimented with was the fluoride, but some interesting results were obtained. As with potassium fluoride, the end-on view showed a predominance of the lines of the gases present, such as carbon dioxide, water-vapor, and chlorine. When a broadside view was taken, however, at a point where the discharge was of a deep-blue color, the lines of rubidium were obtained, and the only other lines present were those due to fluorine, the spectrum of which consists of only a very few lines. The contrast between this spectrum and the arc spectrum of rubidium is very marked, as is shown in Plate I, No. 4.

The *Grundspectrum* appears only quite locally in the capillary tube, as was especially shown in one of the tubes in which the

rubidium fluoride was packed very tightly near one end, and only loosely at the other. A photograph taken with the tube end-on, first one end and then the other, showed a marked increase in the intensity of the lines of the metal, and a decrease in intensity of the lines of the gases present, at the end in which the salt was more closely packed.

As the spectrum was photographed with a quartz instrument of comparatively small dispersion, the wave-lengths could not be obtained very accurately. It soon became evident, however, that all the stronger lines were identical with lines observed in the spark by Exner and Haschek,[1] and the wave-lengths given by these observers have therefore been adopted. These are shown in Table II, together with the relative intensities in the spark and *Grundspectrum*. Other lines believed to belong to the *Grundspectrum* of rubidium, but not recorded in the spark, are shown in Table II*a*, the wave-lengths having been determined by interpolation with respect to neighboring lines given by Exner and Haschek.

### SODIUM

With sodium chloride, the D lines appeared quite strongly, and the presence of spark lines, which are all faint, except those far in the ultra-violet,[2] was very doubtful. The color of the discharge was sometimes the green of chlorine and at others, the yellow of sodium. Thus, although it is possible that greater energy was put into the spark than that employed by Goldstein, the arc spectrum was still the predominant feature in the case of sodium.

The observations of the elements of the potassium group confirm Goldstein's conclusion that the heavier elements give the *Grundspectra* with the greater facility.

### STRONTIUM

In the case of potassium, rubidium, and caesium, it appears that the *Grundspectra* consist only of the enhanced lines, which have not yet been arranged in series. It therefore seemed impor-

[1] *Wellenlängentabellen*, Leipzig und Wien: Funke, 1902.

[2] Eder and Valenta, *Denkschr. Wien. Akad.*, **61** (1894); R. Schillinger, *op. cit.*

tant to examine salts of the calcium group in the same way as in these cases. The enhanced lines are well known and most of

TABLE II

RUBIDIUM

| SPARK (EXNER AND HASCHEK) | | RELATIVE INTENSITIES IN *Grundspectrum* MAX. = 10 |
|---|---|---|
| Wave-Length | Intensity | |
| 4648.75 | 2 | 1 |
| 4622.55 | 1 | ..... |
| 4571.75* | 8 | 5 |
| 4530.50* | 1 | 1 |
| 4378.1 | 1 | 1 |
| 4294.08* | 10 | 5 |
| 4288.20 | 2 | 1 |
| 4273.26* | 3 | 3 |
| 4244.50* | 30 | 10 |
| 4215.73† | 10 | ..... |
| 4201.97† | 30 | ..... |
| 4193.18 | 3 | 3 |
| 4136.55 | 1 | <1 |
| 4132.70 | 2 | 1 |
| 4104.49 | 10 | 5 |
| 4084.05 | 2 | 1 |
| 4029.65 | 1 | 1 |
| 3978.30 | 2 | 1 |
| 3940.62 | 20 | 5 |
| 3927.3 | 1 | <1 |
| 3914.5 | 1 | ..... |
| 3861.40 | 5 | 2 |
| 3851.9 | 3 | 4 |
| 3846.3 | 2 | ..... |
| 3843.8 | 1 | ..... |
| 3833.94 | 1 | ..... |
| 3828.1 | 2 | 1 |
| 3806.0 | 1 | 1 |
| 3802.05 | 2 | 3 |
| 3796.99 | 3 | 3 |
| 3699.98 | 1 | 1 |
| 3664.4 | 1 | 2 |
| 3663.5 | 1 | 2 |
| 3640.55 | 1 | 1 |
| 3601.35 | 3 | 5 |
| 3532.2 | 1 | 1 |
| 3522.2 | 2 | 2 |
| 3492.5 | 1 | 1 |

* Also observed by Goldstein. † Arc doublet—$P_1(4)$ and $P_2(4)$.

them can be arranged in series which differ from ordinary arc line series only in the replacement of the series constant $N$ by the term $4N$.[1]

[1] Fowler, *Phil. Trans. Roy. Soc.*, A **214**, 225, 1914.

The first substance investigated was strontium chloride. The discharge was of the green color characteristic of chlorides, but neither the end-on nor the broadside position showed any trace of strontium lines, and, in fact, one could not hope to get a purer chlorine spectrum than was obtained by photographing from the end-on position.

TABLE II*a*

RUBIDIUM

| Wave-Length | Relative Intensity | Wave-Length | Relative Intensity |
|---|---|---|---|
| 5526* | 1 | 3866.5 | 1 |
| 5152* | 1 | 3856.0 | 3 |
| 4777*† | 2 | 3854.8 | 3 |
| 4267.3‡ | 1 | 3812.3 | 1 |
| 4186.5§ | <1 | 3642.8 | 2 |
| 4117.5 | <1 | 3512.4 | 2 |
| 4109.4 | <1 | 3496.6 | 2 |
| 3867.6 | 1 | 3494.3 | 2 |

* Also observed by Goldstein.

† Given in a later table by Exner and Haschek, *Die Spectren der Elemente bei normalem Druck* (1911).

‡ Carbon(?). § Potassium(?).

An examination of the neighborhood of the tip of the electrode, however, showed the presence of the enhanced strontium line at λ 4216 to a very marked extent. Better results were subsequently obtained by fusing some of the salt on the electrode. This method is an approximation to that originally used by Goldstein, in which the anode was surrounded by the salt. The method was also tried with potassium, but no improvement on the previous results was obtained.

The photographs taken showed the strontium doublets, and only one other strontium line, viz., the strong flame and arc line at λ 4607, whose relative intensity, however, was much diminished. A few of the stronger chlorine lines and the aluminium spark lines also appeared in the spectrum.

Table III shows the extent to which the strontium spectrum became modified by this method.

CALCIUM

In the case of calcium, the fluoride was used, fused into the electrode in the same way as with strontium chloride. By far the

strongest lines in the spectrum were the H and K lines at λ 3969 and λ 3934, forming the first pair of the principal series of doublets. Other enhanced lines appearing were the sharp pair at λ 3737 and λ 3706, whose intensities were rather small, and the diffuse pair at λ 3179 and λ 3159, which appeared quite strongly. The strong arc lines at λ 3645 and λ 3631 totally disappeared, but the well-known flame and arc line at λ 4227 was still present but much decreased in intensity.

TABLE III

STRONTIUM

| *Grundspectrum* | | INTENSITY IN ARC EXNER AND HASCHEK* | SERIES |
|---|---|---|---|
| Wave-Length | Relative Intensity | | |
| 4607 | 100 | 1000 | (Arc line) |
| 4306 | 40 | 20 | Sharp |
| 4216 | 500 | 500 | Principal |
| 4162 | 30 | 20 | Sharp |
| 4078 | 1000 | 1000 | Principal |
| 3475 | 20 | 8 | Diffuse (Sat.) |
| 3465 | 100 | 30 | Diffuse |
| 3381 | 100 | 20 | Diffuse |

* *Die Spectren der Elemente bei normalem Druck.*

On the whole, the phenomena with calcium were less striking than with strontium, but the general result was the same, namely, an approach to conditions under which the enhanced lines occur alone.

BARIUM

In the case of barium, the chloride was used and the results obtained with it were highly satisfactory. The discharge was very brilliant, and even with the 10-inch coil good photographs were obtained. All the spark doublets in the region covered by the photographs were observed, the lines at λ 4554 and λ 4131 being by far the strongest in the spectrum. The pair observed by Runge and Paschen[1] at λ 6497 and λ 5853, which have not yet been fitted into any of the series, was relatively weak.

Arc lines were practically absent, for it was only by making the discharge as brilliant as possible that the bright arc line at

[1] *Astrophysical Journal*, **16**, 133, 1902.

λ 5536 could be observed at all. Table IV shows how striking is the modification of the spectrum.

TABLE IV

BARIUM

| Wave-Length | Intensity in Arc Exner and Haschek* | Intensity in Spark Exner and Haschek* | Intensity in *Grundspectrum* Max. = 1000 | Series |
|---|---|---|---|---|
| 6497 | 200 | 200 | 100 | ..... |
| 6142 | 1000 | 500 | 200 | ..... |
| 5853 | 200 | 100 | 50 | ..... |
| 5536 | 100 | 30 | 20 | (Arc line) |
| 4934 | 100 | 300 | 500 | Principal |
| 4900 | 10 | 100 | 200 | Sharp |
| 4554 | 1000 | 1000 | 1000 | Principal |
| 4525 | 10 | 50 | 200 | Sharp |
| 4283 | 20 | 20 | ..... | (Arc line) |
| 4166 | 10 | 100 | 200 | Diffuse (Sat.) |
| 4131 | 100 | 800 | 1000 | Diffuse |
| 3993 | 100 | 20 | ..... | (Arc line) |
| 3893 | 10 | 500 | 500 | Diffuse |

* *Spectren der Elemente bei normalem Druck* (1911).

Thus, with the calcium group of elements also, the greater the atomic weight of the metal, the greater the modification of the spectrum.

It may be stated that very brilliant phosphorescence effects are obtained with these salts, especially when the pressure is very low.

## THE SPECTRUM OF CHLORINE

It is of interest to note that many of the vacuum-tube lines of chlorine and bromine as tabulated by Eder and Valenta[1] did not appear in the photographs of the chlorides and bromides examined. This is in accordance with Goldstein's[2] observation that some of the strong lines of chlorine and bromine disappear when a large capacity is introduced. The spectra of three or four chlorides having been thoroughly examined, the accompanying list of strong vacuum-tube chlorine lines missing from the spark spectrum of solid chlorides was obtained (Table V).

These lines appear to have been obtained only with weak discharges and doubtless correspond in some way to arc spectra in the case of metals.

[1] *Wien. Denkschr.*, pp. 68, 437, and 523, 1899. [2] *Op. cit.*

A few other lines were very much weakened in these spectra, but did not entirely disappear; notably the lines at λλ 4475.5, 4371.7, 4363.5, 4259.6, and 3868.8.

TABLE V

CHLORINE LINES NOT OBSERVED IN *Grundspectrum* TUBES

| Wave-Length (Eder and Valenta) | Intensity in Vacuum Tube | Wave-Length (Eder and Valenta) | Intensity in Vacuum Tube |
|---|---|---|---|
| 4624.23 | 3 | 4363.457 | 8 |
| 4601.19 | 4 | 4323.523 | 6 |
| 4526.44 | 5 | 4280.615 | 3 |
| 4475.498 | 4 | 4264.740 | 3 |
| 4469.569 | 5 | 4226.580 | 7 |
| 4438.735 | 4 | 4209.866 | 5 |
| 4403.610 | 5 | 4032.330 | 5 |
| 4390.566 | 3 | 3982.060 | 3 |
| 4389.949 | 8 | 3871.537 | 4 |
| 4369.676 | 6 | 3854.000 | 4 |

Again, several other lines were greatly intensified and probably correspond with the enhanced lines of metals. Among these was the strong characteristic triplet at λλ 4819.6, 4810.2, and 4794.6, besides lines at λλ 4132.7, 3991.6, and 3861.0.

## GENERAL CONCLUSION

The chief conclusion to be drawn from the foregoing investigation is that the *Grundspectra* obtained by Goldstein's method consist essentially of lines which are specially developed in the ordinary spark spectrum. With potassium and rubidium, the spectra consist entirely of the enhanced lines, but with the calcium group the last traces of the arc spectrum have not yet been entirely removed. In this connection, it may be noted that the arc spectra of potassium and rubidium contain no spark lines, while in the arc spectrum of the calcium group the spark lines (e.g., the H and K lines of calcium) appear very strongly.

In conclusion, I wish to record my best thanks to Professor Fowler for valuable advice and help during the investigation and in the preparation of the paper.

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October 8, 1914

# ANOMALOUS DISPERSION IN THE SUN IN THE LIGHT OF OBSERVATIONS[1]

By CHARLES E. ST. JOHN

In a series of recent articles[2] Professor Julius has considered the displacements of the Fraunhofer lines at the center and limb edges of eccentrically located sun-spots from the point of view of his theory of anomalous dispersion. For the subject-matter he has used the data published in my paper on "Radial Motion in Sun-Spots."[3] In these articles he sets forth a new deduction from the theory of anomalous dispersion—the "mutual influence" of the Fraunhofer lines upon each other: in particular, that a weak line on the violet side of, and near to, a stronger line is displaced less, but if on the red side more, than the average amount. This deduction offers a means of making a quantitative test of the rôle played by anomalous dispersion in the solar atmosphere. These displacements are well suited for a definitive test of the theory, for they are purely differential, and numerous other lines upon the same plates are available for standards of reference.

Professor Julius selected 82 lines from my published list of displacements at the outer edge of the penumbrae of spots, and he finds that those to the violet of stronger lines are displaced less, and those to the red more, than the average. There are, however, many other lines in my list that fulfil the conditions of selection proposed by Professor Julius. These give results opposite to those obtained from the lines selected by him. Moreover, his treatment of the data in obtaining the normal displacements appears to have involved an error, the effect of which is to introduce residuals of the sign required by his theory. These points will now be given consideration in detail. In such a discussion three things demand attention in order that no systematic errors may be introduced and that proper weight

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 93.

[2] *Versl. kon. akad. v. wetensch. Amsterdam*, **22**, 1243, 1914; *Observatory*, **37**, 252, 1914; *Astrophysical Journal*, **40**, 1, 1914.

[3] *Mt. Wilson Contr.*, No. 69; *Astrophysical Journal*, **37**, 327, 1913.

may be given to crucial cases whose bearing upon the question is of special importance: (1) the determination of the standard displacements; (2) the inclusion of all lines falling within the adopted conditions of selection; (3) consideration of the effects in the immediate neighborhood of strong lines showing in the laboratory marked anomalous dispersion phenomena.

## STANDARD DISPLACEMENTS

The 506 lines of Table I in my first paper[1] do not form a homogeneous series of observations. Attention was called to this point in my discussion of the data. From this it results that the normal displacements for different spectral regions cannot be determined with high precision by deducing them for each region by any smoothing-out process involving the results for all the segregated regions. The following regions were covered by the observations:

*a*) From λ 3624 to λ 3724. Here a few plates were taken with the purpose of obtaining the line λ 3694 assigned by Jewell to ytterbium, as it began to appear probable that the heavy elements would be of particular interest.

*b*) From λ 3879 to λ 4410. This is a homogeneous region, as overlapping plates were obtained by which the observations were interconnected and hence are comparable.

*c*) From λ 4634 to λ 4829. The earlier observations were upon this region, as it was desired first to repeat Evershed's observations. The mean result for all lines in this region is high in comparison with regions on either side; and, of the six regions, it is the one in which the necessity of separate consideration is the greatest, when the behavior of individual lines is to be studied.

*d*) From λ 5123 to λ 5349. This region includes the great magnesium lines of the *b* group.

*e*) From λ 5598 to λ 6065, in order to obtain the D lines of sodium.

*f*) From λ 6393 to λ 6643, to include the $H_\alpha$ line of hydrogen.

To obtain the normal displacements, Professor Julius used the mean displacements for the iron lines grouped into three regions,

[1] *Mt. Wilson Contr.*, No. 69, p. 6; *Astrophysical Journal*, **37**, 333, 1913.

namely: the two violet series, mean λ 4017; the blue-green series, mean λ 4992; and the yellow-red series, mean λ 6121, reproduced in Table I.

TABLE I

DISPLACEMENTS OF IRON LINES

| Region | Intensity | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| λ 4017..... | 0.022 | 0.020 | 0.014 | 0.014 | 0.013 | 0.011 | 0.008 | 0.006 |
| λ 4992..... | 0.030 | 0.026 | 0.026 | 0.025 | 0.018 | 0.016 | 0.006 | 0.007 |
| λ 6121..... | 0.032 | 0.030 | 0.032 | 0.024 | 0.028 | 0.024 | 0.019 | 0.016 |

Using these data, he says:

. . . . On the basis of the two rules found by St. John that connect the displacements with line intensity and with wave-length, it was possible to indicate a "normal" displacement peculiar to the spectral region and the intensity of each measured line. With these normal values the observed values had to be compared.[1]

The method of derivation of the normal displacements is not explicitly stated, but supposedly they were obtained either graphically or analytically from the data given. In either case the derived values would depend upon, and be influenced by, the displacements in the separate regions and would not refer with high precision to any one of the homogeneous regions. The mean displacements for the iron and nickel lines of intensity 2–3 for each of the six spectral regions are plotted in Fig. 1, and the curve drawn with consideration of the weights of the points. Owing to the very large displacements given by the blue region, λ 4634–λ 4829, the normals for the adjoining regions, deduced from the data for all regions, are too large, and for the blue region itself too small. The use of normal displacements interpolated from such a graph might be justifiable, if the lines whose displacements are to be compared with these normals were well distributed over the regions concerned in their derivation. It is evident that if the lines whose displacements are to be compared with such normals are not evenly distributed, but are confined to one or two regions, systematic

[1] *Astrophysical Journal*, **40**, 13, 1914.

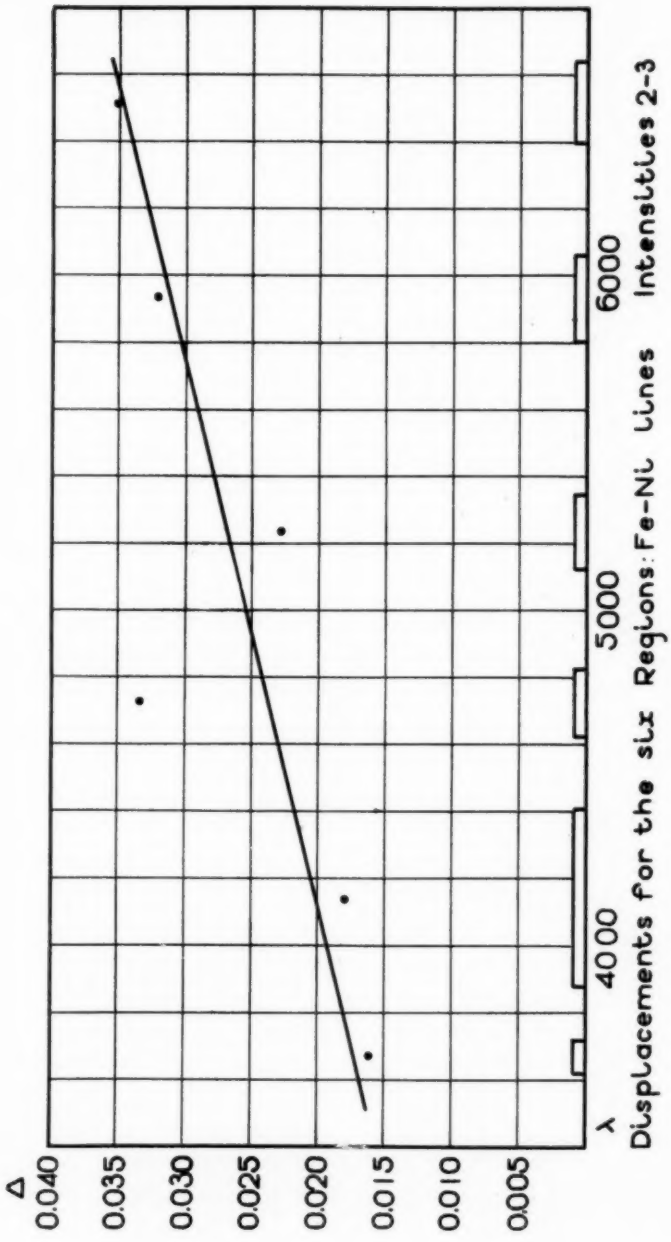
Δ
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
λ
4000
5000
6000
Displacements for the six Regions: Fe-Ni Lines Intensities 2-3

FIG. 1

residuals will result. Moreover, the normal displacements used by Professor Julius are derived from the displacements of the iron lines only. This neglects any differences depending upon individual elements, differences that are real and systematic.

To obtain residuals capable of representing any systematic behavior of lines within the refractive influence of stronger lines, the standard displacements should be derived from the limited homogeneous series of observations in which they are to be used, and, as far as the data permit, they should refer to the particular elements under consideration. Standard displacements of this character have been obtained by determining the mean displacements for the lines of each element of a given intensity for each of the six homogeneous series. In the rare cases where fewer than three lines are available, the mean displacement for all lines of the same intensity in the respective series has been used.

In the first section of Tables II and III are reproduced the data given by Professor Julius for lines on the violet and red sides of stronger lines, respectively. In the eighth column are shown the mean displacements for the lines of the elements of the intensity and region under consideration, and in the ninth the residuals obtained by using these means as standard displacements. In the last column are remarks relative to the character and properties of the influencing lines that bear upon their power to produce the assumed effects.

### ADDITIONAL LINES

Attention has been called to the necessary condition that all lines within the definition of the category be included. Professor Julius says:

> . . . . I selected *all* cases in which a measured line *A* of intensity 3 or lower was on the *violet* side of a stronger line *B* (generally of intensity 4 or higher) at a distance of about 0.5 A or less. A few cases in which the line *A* had another strong companion *B'* equally near but on the other side were of course discarded. Forty-three pairs answering the conditions were found. . . . .[1]

After a definition has been adopted, it is always hazardous to disregard it. The lanthanum line, λ 3995, of intensity 1, is between

[1] *Astrophysical Journal*, 40, 13, 1914.

two lines of intensities 3 and 5, each within the limiting distance of 0.5 A. It is a delicate question to decide whether the line of intensity 3, which is nearer, or the line of intensity 5 is the more influential. The measured displacement of this lanthanum line is small, 0.014 A. It is on the violet side of the weaker line and shows a large negative residual. The decision was in favor of the weaker. The lanthanum line λ4123 shows a large displacement, 0.023 A. It is 0.523 A to the violet of a much stronger line. It is omitted, though favorable cases exceeding the limit by much larger amounts are included. Of the 14 lines included by Professor Julius in which either the distance exceeds 0.5 A, or some one or more of the other limitations are exceeded, two only are unfavorable to the thesis under consideration.

It is a question whether the mutual influence of a blend is the same as that of a single line whose intensity is the sum of the intensities of the constituents; for example, it is at least doubtful whether a line of intensity 5 should be considered susceptible to the influence of a blend consisting of 2 lines each of intensity 3 to the same degree as of a single line of intensity 6, as Professor Julius has apparently done. However this may be, it seems clearly inadmissible to include the influenced line itself in the blend and particularly inadmissible when the influenced line forms the major part of the blend, for then we have the remarkable case of a line displaced by its own influence, as λ 3899.171.

An examination of Rowland's Table shows 49 lines not included by Professor Julius, 24 on the violet and 25 on the red side of stronger lines. Of these additional lines those on the violet are all within the limiting distance of 0.5 A; of those on the red, two exceed it. These two lines are now included, mainly because of their important bearing on the theory of anomalous dispersion: they are a line of intensity 4 at 0.7 A to the red of a line of intensity 20, and a line of intensity 10 at 0.79 A from a line of solar intensity 700. In both cases the anomalous dispersion of the controlling lines is strong and the lines are within the limits used by Professor Julius, as he included the Ni line λ 4703 of intensity 3 at 0.817 A from a line of intensity 10. For the additional lines the normal displacements given by Professor Julius are used for their respective

## TABLE II A

### Fraunhofer Lines to the Violet of Stronger Lines as Selected by Professor Julius

| Lines | Difference | Element | Intensity | Observed Displacement | Julius | | St. John | | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Normal Displacement | Residual | Mean | Residual | |
| 3649.137 | | Cr | 1 | 0.014 | 0.022 | −0.008 | 0.018 | −0.004 | |
| 3649.438 | .301 | ..... | 5 | ..... | ..... | ..... | ..... | ..... | |
| 3662.096 | | Ni | 3 | .015 | .015 | .000 | .015 | .000 | |
| 3662.378 | .282 | (Ti) | 5 | ..... | ..... | ..... | ..... | ..... | |
| 3686.926 | | Cr | 1 | .016 | .022 | − .006 | .018 | − .002 | |
| 3687.234 | .308 | ..... | 3 | ..... | ..... | ..... | ..... | ..... | |
| 3687.234 | | Fe | 3 | .010 | .015 | − .005 | .015 | − .005 | |
| 3687.610 | .376 | Fe | 6 | ..... | ..... | ..... | ..... | ..... | |
| 3688.210 | | V | 1 | .018 | .022 | − .004 | .017 | + .001 | |
| 3688.558 | .348 | ..... | 4 | ..... | ..... | ..... | ..... | ..... | |
| 3690.599 | | Fe | 2 | .017 | .020 | − .003 | .016 | + .001 | |
| 3690.870 | .271 | ..... | 3 | ..... | ..... | ..... | ..... | ..... | |
| 3707.702 | | Ti | 2 | .013 | .020 | − .007 | .016 | − .003 | |
| 3708.07 | .366 | Fe | 6 | ..... | ..... | ..... | ..... | ..... | |
| 3708.964 | | Co | 1 | .015 | .022 | − .007 | .018 | − .003 | |
| 3709.389 | .425 | Fe | 6 | ..... | ..... | ..... | ..... | ..... | |
| 3895.119 | | Co | 3 | .012 | .015 | − .003 | .013 | − .001 | |
| Blend | | ..... | 4? | ..... | ..... | ..... | ..... | ..... | Blend of weak lines |
| 3895.583 | | Mn | 3 | 0.008 | 0.015 | −0.007 | 0.017 | −0.009 | |
| 3895.803 | .220 | Fe | 7 | ..... | ..... | ..... | ..... | ..... | Anomalous dispersion very weak |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 3898.032..... | | Fe | 3 | 0.007 | 0.015 | −0.008 | 0.015 | −0.008 | |
| 3898.2..... | | ..... | 4 | ..... | ..... | ..... | ..... | ..... | Perhaps V5 at 3898.151 |
| 3899.171..... | | Fe | 3 | .013 | .015 | − .002 | .015 | − .002 | A line displaced by its own action as it forms the major portion of the influencing line |
| 3899.21..... | | (V-Fe) | 3 | ..... | ..... | ..... | ..... | ..... | |
| 3906.438..... | | Co | 2 | .010 | .020 | − .010 | .016 | − .006 | |
| 3906.628..... | .190 | Fe | 10 | ..... | ..... | ..... | ..... | ..... | Anomalous dispersion very weak |
| 3913.123..... | | Ni | 2 | .016 | .020 | − .004 | .019 | − .003 | |
| 3913.609..... | .486 | Ti | 5 | ..... | ..... | ..... | ..... | ..... | |
| 3916.879..... | | Fe | 5 | .009 | .014 | − .005 | .014 | − .005 | |
| 3917.324..... | .445 | (Fe) | 6 | ..... | ..... | ..... | ..... | ..... | Intensity 5 |
| 3947.522..... | | ? | 2 | .014 | .021 | − .007 | .019 | − .005 | |
| 3947.675..... | .153 | Fe | 4 | ..... | ..... | ..... | ..... | ..... | |
| 3956.603..... | | Fe | 4 | .010 | .014 | − .004 | .014 | − .004 | |
| 3956.879..... | .276 | Fe | 6 | ..... | ..... | ..... | ..... | ..... | |
| 3958.073..... | | Co | 2 | .018 | .022 | − .004 | .016 | + .002 | |
| 3958.355..... | .282 | (Zr-Ti) | 4 | ..... | ..... | ..... | ..... | ..... | |
| 3962.995..... | | Ti | 3 | .012 | .016 | − .004 | .012 | .000 | |
| 3963.281..... | .286 | ..... | 4 | ..... | ..... | ..... | ..... | ..... | Blend |
| 3995.899..... | | La | 1 | .014 | .023 | − .009 | .022 | − .008 | On the other side is a line of intensity 5, 0.436 A distant, whose effect is neglected |
| 3996.140..... | .241 | ..... | 3 | ..... | ..... | ..... | ..... | ..... | |
| 3997.115..... | | Fe | 2 | .019 | .022 | − .003 | .019 | .000 | |
| 3997.547..... | .432 | Fe | 4 | ..... | ..... | ..... | ..... | ..... | |
| 4035.752..... | | Co | 2 | 0.016 | 0.022 | −0.006 | 0.016 | 0.000 | |
| 4035.883..... | .131 | Mn | 4 | ..... | ..... | ..... | ..... | ..... | Anomalous dispersion strong |

TABLE II A—*Continued*

| Lines | Difference | Element | Intensity | Observed Displacement | Julius | | St. John | | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Normal Displacement | Residual | Mean | Residual | |
| 4109.609..... | | Nd | 1 | 0.016 | 0.024 | −0.008 | 0.022 | −0.006 | |
| 4109.953..... | .344 | ..... | 4 | ..... | ..... | ..... | ..... | ..... | Intensity 3 |
| 4132.100..... | | V | 2 | .011 | .022 | − .011 | .021 | − .010 | |
| 4132.235..... | .135 | Fe | 10 | ..... | ..... | ..... | ..... | ..... | |
| 4133.755..... | | Fe | 2 | .022 | .022 | .000 | .019 | + .003 | |
| 4133.95..... | .255 | (Fe-Ce) | 4 | ..... | ..... | ..... | ..... | ..... | Fe 3 at 4134.010 |
| 4149.360..... | | Zr | 2 | .016 | .022 | − .006 | .018 | − .002 | |
| 4149.533..... | .173 | Fe | 4 | ..... | ..... | ..... | ..... | ..... | |
| 4216.136..... | | CN | 1 | .022 | .024 | − .002 | .018 | + .004 | |
| 4216.351..... | .215 | (Fe) | 4 | ..... | ..... | ..... | ..... | ..... | Intensity 3 |
| 4233.328..... | | (Mn-Fe) | 4 | .017 | .017 | .000 | .014 | + .003 | |
| 4233.772..... | .444 | Fe | 6 | ..... | ..... | ..... | ..... | ..... | |
| 4271.325..... | | Fe | 6 | .009 | .014 | − .005 | .011 | − .002 | |
| 4271.934..... | .609 | Fe | 15 | ..... | ..... | ..... | ..... | ..... | Anomalous dispersion very weak |
| 4274.746..... | | Ti | 2 | .016 | .023 | − .007 | .017 | − .001 | |
| 4274.958..... | .212 | Cr | 7 | ..... | ..... | ..... | ..... | ..... | Anomalous dispersion very strong |
| 4289.525..... | | Ca | 4 | .015 | .019 | − .004 | .016 | − .001 | |
| 4289.885..... | .360 | Cr | 5 | ..... | ..... | ..... | ..... | ..... | Anomalous dispersion very strong |
| 4294.936..... | | Zr | 2 | .018 | .023 | − .005 | .018 | .000 | |
| 4295.29..... | .354 | Dy | 6 | ..... | ..... | ..... | ..... | ..... | Dy? Blend |
| 4302.353..... | | Fe | 2 | 0.019 | 0.023 | −0.004 | 0.019 | 0.000 | |
| 4302.692..... | .339 | Ca | 4 | ..... | ..... | ..... | ..... | ..... | Anomalous dispersion very weak |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 4315.138..... | | Ti | 3 | 0.010 | 0.021 | −0.011 | 0.012 | −0.002 | |
| 4315.262..... | .124 | Fe | 4 | ..... | ..... | ..... | ..... | ..... | |
| 4408.364..... | | V | 2 | .027 | .024 | + .003 | .021 | + .006 | |
| 4408.54..... | .218 | (V) | 4 | ..... | ..... | ..... | ..... | ..... | Fe 3 at 4408.582 |
| 5168.832..... | | Ni | 1 | .026 | .028 | − .002 | .028 | − .002 | |
| 5169.16..... | .323 | (Fe) | 7 | ..... | ..... | ..... | ..... | ..... | Blend |
| 5188.863..... | | Ti | 2 | .015 | .026 | − .011 | .019 | − .004 | |
| 5189.018..... | .155 | Ca | 3 | ..... | ..... | ..... | ..... | ..... | |
| 5226.707..... | | Ti | 2 | .020 | .026 | − .006 | .019 | + .001 | |
| 5227.043..... | .336 | Fe-Cr | 4 | ..... | ..... | ..... | ..... | ..... | Intensity 3 |
| 5250.385..... | | Fe | 2 | .028 | .027 | + .001 | .023 | + .005 | |
| 5250.817..... | .432 | (Fe) | 3 | ..... | ..... | ..... | ..... | ..... | |
| 5298.194..... | | Cr | 1 | .021 | .029 | − .008 | .024 | − .003 | |
| 5298.455..... | .261 | Cr | 4 | ..... | ..... | ..... | ..... | ..... | Anomalous dispersion weak |
| 5598.524..... | | Fe | 1 | .019 | .030 | − .011 | .025 | − .006 | |
| 5598.711..... | .187 | Ca | 4 | ..... | ..... | ..... | ..... | ..... | Anomalous dispersion very weak |
| 5615.520..... | | Fe | 2 | .025 | .027 | − .002 | .023 | + .002 | |
| 5615.877..... | .357 | Fe | 6 | ..... | ..... | ..... | ..... | ..... | |
| 5624.245..... | | Fe | 1 | 0.027 | 0.031 | −0.004 | 0.025 | +0.002 | |
| 5624.769..... | .524 | (Fe) | 4 | ..... | ..... | ..... | ..... | ..... | |
| Mean.... | ..... | ..... | ..... | ..... | ..... | −0.0051A | ..... | −0.0018A | |

## TABLE II B

### Additional Lines to the Violet of Stronger Lines

| Lines | Difference | Element | Intensity | Observed Displacement | Julius | | St. John | | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Normal Displacement | Residual | Mean | Residual | |
| 3630.045 | | Ni | 1 | 0.024 | 0.022 | +0.002 | 0.018 | +0.006 | |
| 3630.492 | .447 | Fe | 4 | ..... | ..... | ..... | ..... | ..... | |
| 3692.364 | | V | 1 | .017 | .022 | − .005 | .017 | .000 | |
| 3692.790 | .426 | Fe | 2 | ..... | ..... | ..... | ..... | ..... | |
| 3692.790 | | Fe | 2 | .020 | .020 | .000 | .016 | + .004 | |
| 3692.170 | .380 | Fe | 3 | ..... | ..... | ..... | ..... | ..... | |
| 3895.377 | | Ti | 2 | .020 | .020 | .000 | .017 | + .003 | |
| 3895.803 | .426 | Fe | 7 | ..... | ..... | ..... | ..... | ..... | |
| 3897.596 | | Fe | 2 | .009 | .020 | − .011 | .019 | − .010 | |
| 3898.032 | .436 | Fe | 3 | ..... | ..... | ..... | ..... | ..... | |
| 4006.304 | | Ni | 1 | .024 | .023 | + .001 | .024 | .000 | |
| 4006.464 | .160 | Fe | 2 | ..... | ..... | ..... | ..... | ..... | |
| 4006.464 | | Fe | 2 | .020 | .022 | − .002 | .019 | + .001 | |
| 4006.776 | .312 | Fe | 3 | ..... | ..... | ..... | ..... | ..... | |
| 4024.726 | | Ti | 3 | .016 | .015 | + .001 | .012 | + .004 | |
| 4024.881 | .155 | Fe | 4 | ..... | ..... | ..... | ..... | ..... | |
| 4070.431 | | Mn | 3 | .023 | .016 | + .007 | .017 | + .006 | |
| 4070.930 | .499 | Fe | 4 | ..... | ..... | ..... | ..... | ..... | |
| 4111.509 | | Ce | 1 | .028 | .024 | + .004 | .022 | + .006 | |
| 4111.940 | .431 | V | 4 | ..... | ..... | ..... | ..... | ..... | |
| 4136.678 | | Fe | 4 | 0.023 | 0.014 | +0.009 | 0.014 | +0.009 | |
| 4137.156 | .478 | Mn | 6 | ..... | ..... | ..... | ..... | ..... | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 4183.480..... | | Zr | 1 | 0.024 | 0.024 | 0.000 | 0.021 | +0.003 | |
| 4183.619..... | .139 | V | 2N | ..... | ..... | ..... | ..... | ..... | |
| 4195.006..... | | Cr | 1 | .020 | .024 | − .004 | .021 | − .001 | |
| 4195.492..... | .486 | Fe | 5 | ..... | ..... | ..... | ..... | ..... | |
| 4277.544..... | | Zr | 0 | .026 | .025 | + .001 | .020 | + .006 | |
| 4277.692..... | .148 | ..... | 2d? | ..... | ..... | ..... | ..... | ..... | |
| 4284.838..... | | Ni | 1 | .030 | .024 | + .006 | .024 | + .006 | |
| 4285.164..... | .326 | Ti | 2 | ..... | ..... | ..... | ..... | ..... | |
| 4289.237..... | | Ti | 2 | .022 | .023 | − .001 | .017 | + .005 | |
| 4289.525..... | .288 | Ca | 4 | ..... | ..... | ..... | ..... | ..... | Anomalous dispersion very weak |
| 4314.964..... | | Ti | 1 | .025 | .024 | + .001 | .023 | + .002 | |
| 4315.138..... | .174 | Ti | 3 | ..... | ..... | ..... | ..... | ..... | |
| 4377.948..... | | Fe | 1 | .030 | .024 | + .006 | .022 | + .008 | |
| 4378.419..... | .471 | | 2Nd? | ..... | ..... | ..... | ..... | ..... | |
| 4708.846..... | | Ti | 2 | .031 | .024 | + .007 | .032 | − .001 | |
| 4709.271..... | .425 | Fe | 3 | ..... | ..... | ..... | ..... | ..... | |
| 4752.289..... | | Ni | 2 | .040 | .024 | + .016 | .037 | + .003 | |
| 4752.613..... | .324 | Ni | 3 | ..... | ..... | ..... | ..... | ..... | |
| 4756.300..... | | Cr | 2 | .026 | .024 | + .002 | .032 | − .006 | |
| 4756.705..... | .405 | Ni | 3 | ..... | ..... | ..... | ..... | ..... | Anomalous dispersion ? |
| 4789.528..... | | Cr | 2 | .034 | .024 | + .010 | .032 | + .002 | |
| 4789.849..... | .321 | Fe | 3 | ..... | ..... | ..... | ..... | ..... | |
| 5148.222..... | | Fe | 2 | .023 | .024 | − .001 | .023 | .000 | |
| 5148.410..... | .188 | Fe | 3 | ..... | ..... | ..... | ..... | ..... | |
| 6496.688..... | | Fe | 2 | 0.037 | 0.031 | +0.006 | 0.033 | +0.004 | |
| 6497.128..... | .440 | Fe | 4 | ..... | ..... | ..... | ..... | ..... | |
| Mean.... | ..... | ..... | ..... | ..... | ..... | +0.0023A | ..... | +0.0025A | |

## TABLE III A

FRAUNHOFER LINES TO THE RED OF STRONGER LINES AS SELECTED BY PROFESSOR JULIUS

| LINES | DIFFERENCE | ELEMENT | INTENSITY | OBSERVED DISPLACEMENT | JULIUS | | ST. JOHN | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Normal Displacement | Residual | Mean | Residual | |
| 3694.24 | .209 | (Fe-Ni) | 8 | | | | | | Blend of intensity 6 at 3694.135 |
| 3694.344 | | Yt | 3 | 0.020 | 0.015 | +0.005 | 0.015 | +0.005 | |
| 3694.344 | .232 | Yt | 3 | | | | | | |
| 3694.576 | | La | 1 | .027 | .022 | + .005 | .018 | + .009 | |
| 3704.603 | .239 | Fe | 4 | | | | | | |
| 3704.842 | | V | 1 | .016 | .022 | − .006 | .018 | − .002 | |
| 3706.24 | .188 | (Mn-Ti-Ca) | 7 | | | | | | Intensity 6 at 3706.175 |
| 3706.363 | | Fe | 3 | .017 | .015 | + .002 | .015 | + .002 | |
| 3711.364 | .188 | Fe | 4 | | | | | | |
| 3711.552 | | Fe | 3 | .015 | .015 | .000 | .015 | .000 | |
| 3898.2 | .380 | | 4 | | | | | | V5 at 3898.151 |
| 3898.531 | | Mn | 2 | .014 | .020 | − .006 | .020 | − .006 | |
| 3947.675 | .243 | Fe | 4 | | | | | | |
| 3947.918 | | Ti | 2 | .013 | .021 | − .008 | .017 | − .004 | |
| 3948.925 | .114 | Fe | 4 | | | | | | |
| 3949.039 | | Ca | 1 | .018 | .022 | − .004 | .022 | − .004 | |
| 3950.102 | .395 | Fe | 15? | | | | | | Intensity 5 |
| 3950.497 | | Y | 5 | .013 | .014 | − .001 | .014 | − .001 | |
| 3984.17 | .203 | (Fe-Mn) | 6 | | | | | | The influenced line is a part of the blend |
| 3984.294 | | Mn | 2 | .021 | .020 | + .001 | .020 | + .001 | |
| 3989.912 | .099 | Ti | 4 | | | | | | |
| 3990.011 | | Fe | 3 | 0.012 | 0.015 | −0.003 | 0.015 | −0.003 | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 4018.25 | .164 | (Mn) | 7 | ..... | ..... | ..... | ..... | ..... | Blend at 4018.256 |
| 4018.420 | | Fe | 3 | 0.022 | 0.015 | +0.007 | 0.015 | +0.007 | |
| 4078.49 | .116 | ? | 4 | ..... | ..... | ..... | ..... | ..... | Fe 4 at 4078.515 |
| 4078.631 | | Ti | 3 | .017 | .016 | + .001 | .012 | + .005 | |
| 4079.4 | .200 | ..... | 5 | ..... | ..... | ..... | ..... | ..... | Blend of Mn 3 and Fe 2 at 4079.370 |
| 4079.570 | | Mn | 3 | .018 | .016 | + .002 | .017 | + .001 | |
| 4134.54 | .300 | (V-Fe) | 6 | ..... | ..... | ..... | ..... | ..... | Blend of two lines of intensity 3 |
| 4134.840 | | Fe | 5 | .014 | .014 | .000 | .014 | .000 | |
| 4161.682 | .279 | (Ti) | 5 | ..... | ..... | ..... | ..... | ..... | Intensity 4 |
| 4161.961 | | Sr | 1 | .025 | .024 | + .001 | .022 | + .003 | |
| 4184.32 | | (Ti-Gd) | 5 | ..... | ..... | ..... | ..... | ..... | The influenced line is a part of the blend |
| 4184.472 | | Ti | 2 | .022 | .022 | .000 | .017 | + .005 | |
| 4196.35 | .327 | ? | 4 | ..... | ..... | ..... | ..... | ..... | Fe 4 at 4196.372 |
| 4196.699 | | La | 2 | .024 | .022 | + .002 | .019 | + .005 | |
| 4236.112 | .317 | Fe | 8 | ..... | ..... | ..... | ..... | ..... | Anomalous dispersion very weak |
| 4236.429 | | Ni | 1 | .024 | .024 | .000 | .024 | .000 | |
| 4240.64 | .332 | (Zr-Ce-Fe) | 4 | ..... | ..... | ..... | ..... | ..... | Intensity 2 at 7240.540 |
| 4240.872 | | Cr | 1 | .022 | .024 | − .002 | .021 | + .001 | |
| 4338.084 | .346 | Ti | 4 | ..... | ..... | ..... | ..... | ..... | |
| 4338.430 | | Fe | 1 | .025 | .024 | + .001 | .022 | + .003 | |
| 4637.685 | .508 | Fe | 5 | ..... | ..... | ..... | ..... | ..... | |
| 4638.193 | | Fe | 4 | .027 | .021 | + .006 | .029 | − .002 | |
| 4667.626 | .142 | Fe | 4 | ..... | ..... | ..... | ..... | ..... | |
| 4667.768 | | Ti | 3 | .027 | .023 | + .004 | .030 | − .003 | |
| 4679.027 | .382 | Fe | 6 | ..... | ..... | ..... | ..... | ..... | |
| 4679.409 | | Ni | 2 | .037 | .024 | + .013 | .037 | .000 | |
| 4703.177 | .817 | Mg | 10 | ..... | ..... | ..... | ..... | ..... | |
| 4703.994 | | Ni | 3 | .035 | .023 | + .012 | .034 | + .001 | |
| 4731.651 | .333 | (Fe) | 4 | ..... | ..... | ..... | ..... | ..... | |
| 4731.984 | | Ni | 1 | 0.030 | 0.026 | +0.004 | 0.036 | −0.006 | |

TABLE III A—*Continued*

| Lines | Difference | Element | Intensity | Observed Displacement | Julius | | St. John | | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Normal Displacement | Residual | Mean | Residual | |
| 4736.963... | .577 | (Fe) | 6 | ..... | ..... | ..... | ..... | ..... | |
| 4737.540... | | Cr | 2 | 0.034 | 0.024 | +0.010 | 0.032 | +0.002 | |
| 4762.567... | .253 | Mn | 5 | ..... | ..... | ..... | ..... | ..... | Anomalous dispersion? |
| 4762.820... | | Ni | 1 | .039 | .026 | + .013 | .036 | + .003 | |
| 5129.42.... | | (Ti-Ni) | 5 | ..... | ..... | ..... | ..... | ..... | The influenced line is a part of the blend |
| 5129.546... | | Ni | 2 | .026 | .024 | + .002 | .024 | + .002 | |
| 5129.546... | .259 | Ni | 2 | ..... | ..... | ..... | ..... | ..... | |
| 5129.805... | | Fe | 1 | .033 | .028 | + .005 | .028 | + .005 | |
| 5131.642... | .300 | (Fe-C) | 3 | ..... | ..... | ..... | ..... | ..... | Intensity 2 |
| 5131.942... | | Ni | 1 | .029 | .028 | + .001 | .028 | + .001 | |
| 5152.087... | .274 | (Fe-C) | 3 | ..... | ..... | ..... | ..... | ..... | |
| 5152.361... | | Ti | 0 | .031 | .031 | .000 | .027 | + .004 | |
| 5192.523... | .616 | (Fe-Nd) | 5 | ..... | ..... | ..... | ..... | ..... | |
| 5193.139... | | Ti | 2 | .021 | .026 | − .005 | .019 | + .002 | |
| 5283.802... | .479 | (Fe) | 6 | ..... | ..... | ..... | ..... | ..... | |
| 5284.281... | | Ti | 1 | .026 | .028 | − .002 | .028 | − .002 | |
| 5298.455... | .217 | Cr | 4 | ..... | ..... | ..... | ..... | ..... | Anomalous dispersion weak |
| 5298.672... | | Ti | 1 | .022 | .028 | − .006 | .028 | − .006 | |
| 5349.652... | .276 | Ca | 4 | ..... | ..... | ..... | ..... | ..... | |
| 5349.928... | | Fe | 1 | .027 | .028 | − .001 | .028 | − .001 | |
| 5857.674... | .302 | Ca | 8 | ..... | ..... | ..... | ..... | ..... | |
| 5857.976... | | Ni | 3 | .030 | .027 | + .003 | .032 | − .002 | |
| 5953.0..... | | (Ti-Fe) | 5 | ..... | ..... | ..... | ..... | ..... | The influenced line is a part of the blend |
| 5953.386... | | Ti | 1 | .038 | .032 | + .006 | .038 | .000 | |
| 6400.217... | .311 | Fe | 8 | ..... | ..... | ..... | ..... | ..... | |
| 6400.528... | | Fe | 2 | 0.026 | 0.031 | −0.005 | 0.035 | −0.009 | |
| Mean... | ..... | ..... | ..... | ..... | ..... | +0.0014A | ..... | +0.0004A | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Mean... | ..... | ..... | ..... | ..... | ..... | +0.0014A | ..... | +0.0004A | |

TABLE III B

ADDITIONAL LINES TO THE RED OF STRONGER LINES

| LINES | DIFFERENCE | ELEMENT | INTENSITY | OBSERVED DISPLACEMENT | JULIUS | | ST. JOHN | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Normal Displacement | Residual | Mean | Residual | |
| 3623.925.... | .333 | Mn-Fe | 4 | ..... | ..... | ..... | ..... | ..... | |
| 3624.258.... | | Ca | 3 | 0.012 | 0.015 | −0.003 | 0.015 | −0.003 | |
| 3645.967.... | .368 | Fe | 4 | ..... | ..... | ..... | ..... | ..... | |
| 3646.335.... | | Ti | 1 | .012 | .022 | − .010 | .018 | − .006 | |
| 3693.170.... | .446 | Fe | 3 | ..... | ..... | ..... | ..... | ..... | |
| 3693.616.... | | Co | 1 | .021 | .022 | − .001 | .018 | + .003 | |
| 3724.526.... | .444 | Fe | 6 | ..... | ..... | ..... | ..... | ..... | |
| 3724.970.... | | Ni | 1 | .018 | .022 | − .004 | .018 | .000 | |
| 3900.681.... | .433 | Ti-Fe-Zr | 5 | ..... | ..... | ..... | ..... | ..... | |
| 3901.114.... | | Ti | 1 | .017 | .023 | − .006 | .023 | − .006 | |
| 3968.625.... | .788 | Ca | 700 | ..... | ..... | ..... | ..... | ..... | Anomalous dispersion strong |
| 3969.413.... | | Fe | 10 | .004 | .003 | + .001 | .003 | + .001 | |
| 3984.091.... | .388 | Cr-Fe | 7 | ..... | ..... | ..... | ..... | ..... | |
| 3984.479.... | | Cr | 2 | .024 | .022 | + .002 | .024 | .000 | |
| 3991.333.... | .247 | Cr-Zr | 3 | ..... | ..... | ..... | ..... | ..... | |
| 3991.580.... | | Fe | 1 | .020 | .023 | − .003 | .022 | − .002 | |
| 3992.971.... | | V-Cr | 3 | ..... | ..... | ..... | ..... | ..... | |
| 3993.246.... | .275 | Fe | 2 | .025 | .022 | + .003 | .019 | + .006 | |
| 4020.424.... | .123 | ..... | 2 | ..... | ..... | ..... | ..... | ..... | |
| 4020.547.... | | Sc | 1 | .014 | .023 | − .009 | .022 | − .008 | |
| 4023.533.... | .301 | Co | 3 | ..... | ..... | ..... | ..... | ..... | |
| 4023.834.... | | Sc | 2 | .026 | .022 | + .004 | .020 | + .006 | |
| 4118.708.... | .226 | Fe | 5 | ..... | ..... | ..... | ..... | ..... | |
| 4118.934.... | | Co | 4 | 0.013 | 0.015 | −0.002 | 0.015 | −0.002 | |

TABLE III B—*Continued*

| Lines | Difference | Element | Intensity | Observed Displacement | Julius | | St. John | | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Normal Displacement | Residual | Mean | Residual | |
| 4137.567 | .242 | | 2 | | | | | | |
| 4137.809 | | Fe, Ce | 1 | 0.014 | 0.024 | −0.010 | 0.022 | −0.008 | |
| 4150.411 | .197 | | 4 | | | | | | |
| 4150.608 | | Co | 1 | .017 | .024 | − .007 | .022 | − .005 | |
| 4196.699 | .138 | La | 2 | | | | | | |
| 4196.837 | | Fe | 1 | .020 | .022 | − .002 | .022 | − .002 | |
| 4224.673 | .347 | Cr-Fe | 3 | | | | | | |
| 4225.020 | | Cr | 2 | .021 | .023 | − .002 | .022 | − .001 | |
| 4226.904 | .702 | Ca | 20 | | | | | | Anomalous dispersion very strong |
| 4227.606 | | Fe | 4 | .010 | .017 | − .007 | .014 | − .004 | |
| 4261.891 | .251 | | 2 | | | | | | |
| 4262.142 | | Cr | 1 | .024 | .024 | .000 | .022 | + .002 | |
| 4273.482 | .161 | Fe | 3N | | | | | | |
| 4273.643 | | Zr | 2N | .021 | .023 | − .002 | .020 | + .001 | |
| 4289.885 | .492 | Cr | 5 | | | | | | Anomalous dispersion very strong |
| 4290.377 | | Ti | 2 | .013 | .023 | − .010 | .017 | − .004 | |
| 4295.914 | .130 | Cr-Ti | 2 | | | | | | |
| 4296.044 | | Ni | 1 | .020 | .024 | − .004 | .024 | − .004 | |
| 4304.729 | .153 | | 2 | | | | | | |
| 4304.882 | | Zr | 0 | .020 | .025 | − .005 | .020 | .000 | |
| 4359.784 | .123 | Cr | 3 | | | | | | Anomalous dispersion very weak |
| 4359.907 | | Zr | 0 | .019 | .025 | − .006 | .020 | − .001 | |
| 4400.555 | .183 | Sc | 3 | | | | | | |
| 4400.738 | | V | 1 | .021 | .024 | − .003 | .022 | − .001 | |
| 4786.727 | .276 | Ni | 3 | | | | | | |
| 4787.003 | | Fe | 2 | 0.025 | 0.024 | +0.001 | 0.030 | −0.005 | |
| Mean | | | | | | −0.0034A | | −0.0017A | |

intensities and spectral regions. In a few cases in which a direct transfer could not be made, the normals are interpolated from those used by Professor Julius.

The negative residual of −0.0051 A found by Professor Julius for the 43 lines to the violet is reduced to −0.0018 A when the displacement for each line is compared with the mean for the element, intensity, and region; but if all lines to the violet are taken into account, the corresponding mean residuals are −0.0024 A and −0.0003 A. When all lines to the red of stronger lines are considered, the mean residual is practically zero whichever standard is used. The results are assembled in Table IV.

TABLE IV

RESIDUALS GIVEN BY WEAK SOLAR LINES NEAR STRONGER LINES

| LINES TO VIOLET | | | LINES TO RED | | |
|---|---|---|---|---|---|
| | According to | | | According to | |
| | Julius | St. John | | Julius | St. John |
| 43 original | −0.0051 | −0.0018 | 39 original | +0.0014 | +0.0004 A |
| 24 additional | + .0023 | + .0025 | 25 additional | − .0034 | − .0017 |
| Weighted mean | −0.0024 | −0.0003 | Weighted mean | −0.0005 | −0.0004 |

A comprehensive impression may be obtained by combining the residuals derived in this paper as in Table V.

TABLE V

| | Lines to Violet | Lines to Red | Total |
|---|---|---|---|
| Sum of favorable residuals | −0.125 | +0.087 | 0.212 A |
| Sum of unfavorable residuals | +0.105 | −0.113 | .218 |
| Unfavorable excess from 131 lines | | | .006 |
| Mean excess per line | | | 0.00005 |

This confirms the conclusion expressed in my second paper on "Radial Motion in Sun-Spots" that until we are able to depend upon solar wave-lengths to the fourth decimal place, at least, the contribution of anomalous dispersion to the relative positions of Fraunhofer lines, if any, will be masked by phenomena due to other causes.

## SYSTEMATIC ERRORS

The results obtained by Professor Julius will now be discussed in the light of the systematic errors that appear to have been introduced by the method used by him in obtaining the normal displacements.

By referring to the graph in Fig. 1, or to a somewhat similar graph in the paper by Professor Julius,[1] it will be seen that normal displacements derived by combining the observations of the six series are too high for the violet and green regions because of the very large displacements given by the blue region, λ 4634–λ 4829.

In Table VI are given the residuals obtained by comparing the normal displacements used by Professor Julius with the mean displacements of all lines of the corresponding intensities in the respective regions.

TABLE VI

COMPARISON OF THE JULIUS NORMALS WITH THE MEANS FOR ALL LINES OF LIKE INTENSITY

| Region | Intensity | Means | Normals | Residuals | Mean |
|---|---|---|---|---|---|
| Violet | 1 | 0.0205 | 0.0220 | −0.0015 A | −0.0022 A |
| | 2 | .0182 | .0218 | − .0036 | |
| | 3 | .0147 | .0159 | − .0012 | |
| | 4 | .0140 | .0167 | − .0027 | |
| Blue | 1 | .0376 | .026 | + .0116 | + .0093 |
| | 2 | .0322 | .024 | + .0082 | |
| | 3 | .0334 | .023 | + .0104 | |
| | 4 | .0281 | .021 | + .0071 | |
| Green | 1 | .0275 | .0285 | − .0010 | −0.0024 |
| | 2 | 0.0225 | 0.0263 | −0.0038 | |

Of the 43 lines on the violet side of strong lines, 35 are in the violet region and 8 in the green, so that for these lines the residuals must of necessity be systematically negative, and this accounts in great part for the mean negative residual of −0.0051 A. Of the 24 additional lines, 19 are in the violet and green regions, so that of the 67 lines on the violet side of stronger lines 62 are in the regions where the normals derived from a consideration of the displacements

[1] *Astrophysical Journal*, **40**, 23, Fig. 6, 1914.

for all regions are too high; and the systematic errors introduced account for the final negative value −0.0024 A, when such normals are used, for it is evident from Table VI that any large group of lines selected at random from the violet and green regions must yield a mean negative residual of about −0.0023 A.

On the other hand, of the 39 lines on the red side of stronger lines some occur in each spectral region and the systematic residuals are less in evidence because of the more even distribution of the lines. It is illuminating, however, to consider them somewhat in detail. Of the 39 lines 7 are in the blue region, λ 4634–λ 4829, where the derived normals are too small and hence the residuals are necessarily positive. In fact, for these 7 lines the sum of the residuals is +0.063 A, while for the other 32 lines the sum is −0.005 A. It is evident from Table VI that a few lines from the blue region will furnish positive residuals sufficient to overbalance the negative residuals that the other 32 lines yield. It is equally evident that no weight can be given to these seven positive residuals of mean magnitude +0.009 A when the 22 other lines of the same elements and intensities in this region that are not on the red side of stronger lines give a mean residual of +0.009 A, precisely the same as that given by the lines within the limiting distance of stronger lines. In fact, it is impossible to select 7 lines from the 29 of the same elements and intensities that would not give a mean positive residual irrespective of their distance from stronger lines. When all the lines to the red are taken into the reckoning, they are fairly well distributed, and when so large a number is involved, the errors introduced by the normal displacements used by Professor Julius cease to be systematic and the positive residual disappears.

## MUTUAL INFLUENCE AND LABORATORY RESULTS

The third point requiring attention is whether the mutual influence exerted by a strong line on a weak one in the solar atmosphere varies with the amount of anomalous dispersion manifested by the strong line under terrestrial conditions. The exaggerated importance ascribed to the possible effects of anomalous dispersion

in the solar atmosphere apparently arose from the fact that anomalous dispersion was first studied in the laboratory with the D lines of sodium which show it to an enormous degree, and the suggestion that such a phenomenon must be of influence in the solar atmosphere seemed to foreshadow great possibilities. Later investigation has shown that the anomalous dispersion possessed by the two sodium lines is exceptional and that few lines show it to a marked degree. Geisler has investigated some 300 lines belonging to 25 elements and found the following results:[1]

| | Anomalous Dispersion | | | | | |
|---|---|---|---|---|---|---|
| | Very Strong | Strong | Medium | Weak | Very Weak | ? |
| No. of lines..... | 9 | 17 | 34 | 80 | 123 | 36 |

The effect in the case of the sodium lines is so large that they cannot be included in a scale adjusted to the other lines. In view of the rarity of strong anomalous dispersion, it seems probable that the effect, in the few cases where weak lines are under the influence of strong lines showing anomalous dispersion to a high degree, would stand out clearly in contrast to the instances where the anomalous dispersion of the influencing line is unknown or very weak. It was with such a comparison in view that care was taken to include among the additions the line of intensity 4 at 0.7 A to the red of the line λ 4226.9 of calcium, intensity 20, which shows very strong anomalous dispersion, and the iron line λ 3969 of intensity 10 which is 0.788 A to the red of the H line of calcium, intensity 700. This calcium line has strong anomalous dispersion, and its "dispersion band" is some 10 or 12 A broad. Professor Julius has given an explanation of the calcium flocculi, of the progressive changes in the wave-lengths of the H and K lines in passing from the center to the limb, and of the great wings of these lines, based upon their anomalous dispersion. It would seem that the neighborhood of such lines is precisely the place where the mutual influence would manifest itself, and any failure here bears heavily

[1] *Zeitschrift für wissenschaftliche Photographie*, **7**, 89, 1909.

against the theory. There are 5 Fe lines of intensity 10 measured in the violet region, namely:

| A | Radial Displacement | |
|---|---|---|
| 3906 | 0.003 A | |
| 3969 | 0.004 | 0.79 A to red of |
| 4132 | 0.002 | calcium H, in- |
| 4260 | 0.003 | tensity 700 |
| 4404 | 0.003 | |
| | 0.003 A | |

The remarkable thing is not the divergence in the displacements, but the extraordinary agreement. The iron line $\lambda$ 4227 of intensity 4 is 0.7 A to the red of the calcium line 4226.9 of intensity 20. The calcium line shows very strong anomalous dispersion, but the residual for the iron line is −0.007 A or −0.004 A, according to whether the normals of Professor Julius or the means for Fe lines of intensity 4 in this region are used as standards of reference.

The comparative behavior of weak lines under the influence of strong lines showing great anomalous dispersion, and of those under the influence of strong lines showing weak and very weak anomalous dispersion, would seem to be of great importance and to deserve particular attention in the effort to establish a theory of mutual influence depending upon anomalous dispersion.

The data for such lines appear in Table VII, where the means show no systematic variation in the residuals depending upon the extreme differences in the anomalous dispersion exhibited by the influencing lines under laboratory conditions; and as there is no systematic difference between these residuals and those involving all the lines, it appears that the influencing lines showing either great or small anomalous dispersion produce neither more nor less effect than those manifesting it in a moderate degree.

## ADDITIONAL MEASUREMENTS

So far the criterion of mutual influence has been applied only to the data given by the 506 lines of my original table. Since the announcement of the deduction of mutual influence new measures have been made upon the plates. In making the original series of

measurements, lines in the near neighborhood of very strong lines were in general omitted from the observing program, but in the case of elements represented by few lines, these were measured wherever found. In this new series the measures have been extended to all lines in the near neighborhood of strong lines showing great anomalous dispersion. The measurements have been

TABLE VII

ANOMALOUS DISPERSION OF INFLUENCING LINES

| λ | VERY STRONG AND STRONG | | λ | WEAK, VERY WEAK, AND ? | | |
|---|---|---|---|---|---|---|
| | Julius | St. John | | Julius | St. John | |
| 4035... | −0.006 | 0.000 | 3895.. | −0.007 | −0.009 | |
| 4274... | − .007 | − .001 | 3906.. | − .010 | − .006 | |
| 4289... | −0.004 | −0.001 | 4271.. | − .005 | − .002 | To the violet of stronger lines |
| | | | 4289.. | − .001 | + .005 | |
| | | | 4302.. | − .004 | .000 | |
| | | | 4756.. | + .002 | − .006 | |
| | | | 5298.. | − .008 | − .003 | |
| | | | 5598.. | −0.011 | −0.006 | |
| Mean | −0.0057 | −0.0007 | ..... | −0.0055 | −0.0034 | |
| 3969... | +0.001 | +0.001 | 4236.. | 0.000 | 0.000 | |
| 4227... | −0.007 | −0.004 | 4290.. | − .010 | − .004 | |
| | | | 4359.. | − .006 | − .001 | To the red of stronger lines |
| | | | 4762.. | + .013 | + .003 | |
| | | | 5298.. | − .006 | − .006 | |
| | | | 5857.. | +0.003 | −0.003 | |
| Mean | −0.0030 | −0.0015 | ..... | −0.0010 | −0.0018 | |

made only upon a few plates of the best quality and include many lines extremely difficult to measure with precision, so that large accidental variations may be expected and the statistical method must be relied upon to determine probable results.

A few observations have also been made upon a large symmetrical spot that appeared on the eastern limb of the sun August 13, 1914. Measures of these plates are combined with those from the first series and are given in Tables VIII and IX. The displacements of 144 lines have been measured, of which 16 are within 1 A of the

very strong lines showing great anomalous dispersion. For standards of reference the mean displacements for all lines of a given intensity were used. For each line within 1 A of the strong lines, there are, on an average, 8 lines of the same intensity beyond this limit, upon which the standard displacement depends. If mutual influence produces a measurable effect, this effect should be increasingly manifest as the influencing lines are approached and should reach its maximum value in their near neighborhood. Within 1 A of these strong lines there are 8 lines to the violet showing a mean residual of +0.0006 A based upon 51 measures; there are 8 lines to the red showing a mean residual of +0.0003 A based upon 62 measures. The result then is practically zero, and it seems improbable that an effect of the order assumed by Professor Julius could fail to give an indication of its presence. The results given in Tables VIII and IX show no systematic variation as one approaches the influencing lines, nor any systematic difference between the displacement of lines on the violet and red sides of the strong lines. Observations will be made during the approaching spot maximum upon a larger number of spots, with particular attention to lines under the possible influence of stronger lines, and the mass of data greatly increased; but as far as the present observations are concerned, they fail to show a dependence of mutual influence upon the intensity of the controlling lines, upon their power to produce anomalous dispersion effects, or upon the nearness of the influenced lines.

## ANOMALOUS DISPERSION IN THE LABORATORY AND IN THE SUN

The following extract from one of the earlier papers of Professor Julius gives the idea that he himself was at that time under the impression that a straightforward comparison could be made between laboratory results for anomalous dispersion and solar phenomena:

> A careful examination of the anomalous dispersion of a great number of substances will, of course, have to be made before it can be made out in how far our view will account for the facts already known or yet to be revealed in the chromosphere spectrum. Amongst other things, it must then appear

## TABLE VIII

RESIDUALS FOR LINES TO THE VIOLET OF MUCH STRONGER LINES SHOWING LARGE ANOMALOUS DISPERSION

| Influencing Line | Element | Intensity | Distance 0–1 A | Residual | Distance 1–2 A | Residual | Distance 2–3 A | Residual | Distance 3–5 A | Residual |
|---|---|---|---|---|---|---|---|---|---|---|
| 3933.825 | Ca | 1000 | | | 1.040 | −0.006 | 2.556 | −0.008 | 3.375 | −0.001 |
| | | | | | 1.664 | − .016 | | | 3.803 | − .004 |
| | | | | | | | | | 4.328 | − .004 |
| | | | | | | | | | 4.462 | − .004 |
| | | | | | | | | | 4.565 | − .004 |
| 3944.160 | Al | 15 | 0.439 | +0.001 | | | | | | |
| | | | .671 | + .002 | | | | | | |
| | | | .838 | + .016 | | | | | | |
| | | | .922 | + .012 | | | | | | |
| 3961.674 | Al | 20 | .393 | − .001 | 1.252 | + .002 | | | | |
| 3968.625 | Ca | 700 | | | 1.055 | − .008 | 2.413 | − .006 | 3.962 | − .003 |
| | | | | | 1.847 | − .004 | 2.556 | − .005 | 4.209 | − .002 |
| | | | | | 1.978 | − .008 | 2.970 | −0.003 | 4.794 | +0.002 |
| 4077.885 | Sr | 8 | .926 | .000 | 1.093 | − .003 | | | | |
| | | | | | 1.241 | − .001 | | | | |
| | | | | | 1.510 | − .004 | | | | |
| | | | | | 1.784 | − .001 | | | | |
| 4226.904 | Ca | 20 | .320 | − .005 | 1.030 | − .003 | | | | |
| | | | 0.788 | −0.004 | 1.285 | −0.003 | | | | |
| Weighted mean | | | | +0.0006 | | −0.0038 | | −0.0054 | | −0.0023 |
| No. of lines | | | | 8 | | 12 | | 4 | | 8 |
| No. of measures | | | | 51 | | 67 | | 25 | | 44 |

## TABLE IX

RESIDUALS FOR LINES TO THE RED OF MUCH STRONGER LINES SHOWING ANOMALOUS DISPERSION

| Influencing Line | Element | Intensity | Distance 0–1 A | Residual | Distance 1–2 A | Residual | Distance 2–3 A | Residual | Distance 3–5 A | Residual |
|---|---|---|---|---|---|---|---|---|---|---|
| 3933.825 | Ca | 1000 | | | 1.638 | −0.010 | 2.140 | −0.002 | 3.654 | −0.002 |
| | | | | | | | 2.296 | − .009 | 4.335 | − .005 |
| | | | | | | | | | 4.614 | − .004 |
| | | | | | | | | | 4.727 | − .001 |
| 3944.160 | Al | 15 | 0.724 | +0.002 | 1.100 | + .002 | | | | |
| | | | .873 | + .001 | 1.198 | + .008 | | | | |
| | | | .968 | + .002 | 1.313 | + .001 | | | | |
| | | | | | 1.833 | − .001 | | | | |
| 3961.674 | Al | 20 | .815 | − .001 | 1.321 | + .001 | | | | |
| | | | | | 1.578 | − .005 | | | | |
| 3968.625 | Ca | 700 | .788 | + .001 | 1.159 | − .002 | 2.850 | −0.004 | 3.688 | − .009 |
| | | | | | 1.274 | − .008 | ..... | ..... | 4.095 | .000 |
| | | | | | 1.794 | − .004 | ..... | ..... | 4.431 | +0.006 |
| | | | | | 1.915 | − .004 | | | | |
| 4077.885 | Sr | 8 | .630 | − .001 | 1.685 | − .003 | | | | |
| | | | .746 | + .004 | | | | | | |
| 4226.904 | Ca | 20 | 0.702 | −0.004 | 1.199 | − .003 | | | | |
| | | | | | 1.975 | −0.002 | | | | |
| Weighted mean | ..... | ..... | ..... | +0.0003 | ..... | −0.0018 | ..... | −0.0049 | ..... | −0.004 |
| No. of lines | ..... | ..... | ..... | 8 | ..... | 14 | ..... | 3 | ..... | 7 |
| No. of measures | ..... | ..... | ..... | 62 | ..... | 84 | ..... | 21 | ..... | 37 |

whether those elements whose lines are most conspicuous in the chromosphere light do actually cause uncommonly great anomalous dispersion—a wide field for experimental research, the exploration of which has only just commenced.[1]

A comparison between Geisler's results and the latest flash spectrum data of Mitchell shows, however, that lines showing very small anomalous dispersion in the laboratory are often conspicuous in the chromospheric spectrum, while lines exhibiting it to a high degree in the laboratory may fail in conspicuousness. The lines of the violet magnesium triplet at λ 3833, intensities 10, 15, and 25, are assigned heights of 6000–7000 km, while neighboring lines of mean intensity 5 show a mean height of 600 km. Though the magnesium lines show weak anomalous dispersion and are only four times as strong, they show heights nearly tenfold as great as the comparison lines. The Fe line λ 3860, intensity 20, anomalous dispersion weak, has a height of 6000 km. Comparison lines of mean intensity 6 show a mean height of 800 km. The D lines of sodium show the phenomenon in the laboratory to an enormous degree. Mitchell finds their height to be 1000 km, while neighboring lines of mean intensity 5 upon the same plate are given a mean height of 360 km; so that the D lines, though 5 times as strong, produce arcs only about 3 times as long as the comparison lines. Of the calcium lines, λ 4226.9 shows anomalous dispersion to the highest degree; it is given a height of 5000 km against 14,000 km for the H and K lines, which show less anomalous dispersion. The two factors that appear to be more consistently effective than anomalous dispersion in producing conspicuous chromospheric reversals of the Fraunhofer lines seem to be great normal intensity and enhancement under reduced pressure.

When Mr. Adams made a direct and apparently rational comparison between laboratory results and displacements at the limb and could find no relation between them, it was answered that such a simple comparison could not serve the purpose, because a peculiar feature of the explanation from the point of view of anomalous dispersion is that both very strong and very weak anomalous dispersion make the displacements small, whereas intermediate values give larger displacements. It is of interest to apply this new cri-

[1] *Astrophysical Journal*, **12**, 194–195, 1900.

terion to the displacements found by Mr. Adams. The results based upon the same lines that Mr. Adams used are as follows. The figures in parentheses show the number of lines involved in the comparison:

| | Anomalous Dispersion | | | |
|---|---|---|---|---|
| | Strong | Moderate | Weak | Very Weak |
| Displacements.... | +0.006 A (21) | 0.002 A (2) | 0.0044 A (13) | 0.0061 A (30) |

The contradiction between theory and observation appears quite evident.

As the displacements at the edge of the penumbrae of eccentrically located sun-spots were considered by Professor Julius to be due to anomalous dispersion, it seemed of interest to apply the foregoing criterion to these displacements. The results were unfavorable to the dispersion theory as I apprehended it. It is now shown by Professor Julius that the criterion did not fit this case, but that the test of mutual influence is to apply. In my list of 506 lines there are 131 lines in the near neighborhood of stronger lines, that is, under the influence of these lines, but they show no systematic differences from lines not so situated.

It is worthy of note that Professor Julius takes no account of laboratory results when considering center and limb displacements; but to prove that very strong and very weak anomalous dispersion make the displacements small and that intermediate values give larger displacements, he classifies the lines simply according to line-intensity, irrespective of their known anomalous dispersion. This appears to assume that anomalous dispersion is proportional to line intensity. Likewise, there is no attempt to correlate the effects of mutual influence with what is known of the power of the influencing lines to produce anomalous dispersion phenomena. It seems again to be assumed that all lines of the same intensity are equally effective. The behavior of the great winged lines of magnesium and of many of the strongest lines of iron whose cores are bounded by broad shadings seems to contradict the assumption. These wings

or shadings are explained as "dispersion bands" and it seems probable that their breadth and intensity would bear a direct relation to the power of the lines to produce anomalous dispersion effects; but the lines referred to show weak or very weak anomalous dispersion. The D lines of sodium showing anomalous dispersion out of all proportion to other lines are not bordered by shadings that are proportionately conspicuous or that are comparable with those bordering the H and K lines of calcium. The extent and intensity of the wings appear to depend upon the strength of a line and upon the form of its emission-curve rather than upon the amount of its anomalous dispersion. The disappearance of the wings at the limb, a very striking phenomenon, has as yet received no explanation from the point of view of anomalous dispersion.

In Professor Julius' last paper[1] he seems to have freed the anomalous dispersion theory from the ordinary canons for correlating laboratory and solar observations on the ground that the relations of anomalous dispersion are peculiar to itself, so that it becomes increasingly difficult to correlate the two classes of phenomena. Taken in connection with the great flexibility of the theory this renders it difficult of proof or disproof by observations.

## THE RELATIVE LEVEL OF THE ELEMENTS

Professor Julius says: "St. John attempts to corroborate his intensity-and-level hypothesis by considering the atomic weight of the elements in connection with the displacements of their lines in the spot spectrum. We may doubt whether the data suffice for the purpose."

He refers to a statement of mine, where I say: "But on the chart it will be noticed that the lines of the heavy elements, such as barium, lanthanum, neodymium, cadmium, cerium, lead, and ytterbium, originate at lower levels than the lines of like intensity of iron." I regret that I made the mistake of writing neodymium instead of niobium, and I am glad to have the error called to my attention. On the chart the lines of neodymium are not below those of iron of the same intensity.

[1] *Astrophysical Journal*, **40**, 19–20, 1914.

Professor Julius says further: "But if we refer to Table I of the first paper we find that the evidence is not very strong." As Professor Julius has raised the question, it may be well to present the facts relating to the heavy elements in some detail.

In comparing the displacements of the lines of the heavy elements with those of iron, Professor Julius falls again into the error of using displacements of the iron lines deduced from the six separated regions, though 19 of the 21 lines of the heavy metals are in the violet, for which region the generalized iron scale is slightly high. The correct procedure is, of course, to compare these displacements with those for iron in the same spectral region and measured upon the same or interconnected plates, as in Table X.

TABLE X

DISPLACEMENTS OF THE HEAVY ELEMENTS COMPARED WITH IRON

| Element | Intensity | λ | Observed | Mean for Fe | Residuals | Residuals by Elements |
|---|---|---|---|---|---|---|
| Ba..... | 2 | 4130 | 0.027 | 0.020 | +0.007 | +0.005 |
| | 5 | 5853 | .029 | .026 | + .003 | |
| Ce..... | 1 | 4111 | .028 | .022 | + .006 | |
| | 3 | 4129 | .022 | .014 | + .008 | + .002 |
| Fe, Ce.. | 1 | 4137 | .014 | .022 | − .008 | |
| Cd..... | 3 | 4678 | .038 | .033 | + .005 | + .005 |
| La..... | 2 | 3628 | .019 | .018 | + .001 | |
| | 1 | 3694 | .027 | .022 | + .005 | |
| | 1 | 3995 | .014 | .022 | − .008 | |
| | 1 | 4086 | .026 | .022 | + .004 | |
| | 2 | 4123 | .023 | .020 | + .003 | + .002 |
| | 2 | 4196 | .024 | .020 | + .004 | |
| | 4 | 4204 | .020 | .014 | + .006 | |
| | 2 | 4287 | .019 | .020 | − .001 | |
| | 1 | 4333 | .026 | .022 | + .004 | |
| Nd?.... | 2 | 3994 | .020 | .017 | + .003 | |
| | 1 | 4109 | .016 | .022 | − .006 | .000 |
| | 1 | 4116 | .025 | .022 | + .003 | |
| Nb..... | 1 | 4232 | .030 | .020 | + .010 | + .010 |
| Pb..... | 1 | 4387 | .026 | .020 | + .006 | + .006 |
| Yt..... | 3 | 3694 | 0.020 | 0.014 | +0.006 | +0.006 |

Of the 21 lines 3 show large negative residuals: λ 3995, a nebulous and difficult line of intensity 1 belonging to lanthanum; λ 4137,

a line attributed to cerium, where the negative evidence seems to Professor Julius to deserve being italicized; and a line of neodymium. In regard to the cerium line, a reference to Rowland's Table would have shown that it may as well be called an iron as a cerium line. It was placed upon the observing list through an inadvertence and has not been treated as a cerium line in any discussion. I regret that the full Rowland identification was omitted from the table and that the cerium line λ 4111 appears by a typographical error under the cobalt symbol. The La line λ 3995 is between lines of intensities 3 and 5. Professor Julius has evidently judged that its large negative residual is due to its being on the violet side of the line of intensity 3, but the line λ 4137 is less than a fourth of an angstrom to the red of a stronger line and therefore according to the anomalous dispersion theory should give a positive residual. The residual is large and negative. As to the neodymium lines, it is well known that their identification is only suggested and rests upon no accepted evidence.

The emphasis that Professor Julius places upon these negative residuals leads one to remark that there are two distinct plans for an investigation such as I undertook. One can select a few lines well adapted to measurement and, by concentrating upon them, results of very high accuracy may be obtained; but in that case everything depends upon the selection of the lines. On the other hand, the investigation may be extended, as in this instance, to a wide range of elements and lines. For elements represented by many lines a selection was possible, but for the heavy elements all lines were measured. In such an extended investigation dependence must be placed upon means obtained by statistical treatment, and these in the case of the heavy elements shows such a preponderance of positive residuals that the general result appears to be established by the observations. Professor Julius raises the question of zircon. The measurement of the weak zircon lines in the solar spectrum is particularly difficult. The facts are given in Table XI.

The situation is not quite so bad as Professor Julius puts it. He implies that six of seven lines give decidedly negative residuals when compared with iron. But the evidence given by the mean of the first five in the list is quite indecisive. Two of the remaining three

are close to the red side of stronger lines and should, according to the dispersion theory, give positive residuals; these residuals are, however, −0.004 A and −0.005 A. These two lines, as well as λ 4137, must then, from the point of view of anomalous dispersion, be affected by errors of observation. The remaining is represented in neither the arc nor spark spectrum of zircon.[1] I regret that by a typographical error the line λ 4277 appears in the table as a Cr line.

TABLE XI

COMPARATIVE DISPLACEMENTS OF THE ZIRCON AND IRON LINES

| A | Intensity | Observed | Mean for Fe | Residual |
|---|---|---|---|---|
| 4149 | 2 | 0.016 | 0.020 | −0.004 |
| 4183 | 1 | .024 | .022 | + .002 |
| 4273 | 2 | .021 | .020 | + .001 |
| 4277 | 0 | .026 | .024 | + .002 |
| 4294 | 2 | .018 | .020 | − .002 |
| 4304 | 0 | .020 | .024 | − .004 |
| 4359 | 0 | .019 | .024 | − .005 |
| 4374 | 0 | 0.015 | 0.024 | −0.009 |

In this connection it is of interest to consider an element whose level is higher than iron. When the displacements of the titanium lines are compared with those of iron of the same intensity and spectral region the result is as in Table XII.

TABLE XII

DISPLACEMENTS OF TITANIUM COMPARED WITH THOSE OF IRON

| Intensity | No. of Lines | Mean Ti-Fe |
|---|---|---|
| 0 | 6 | −0.0020 A |
| 1 | 7 | − .0024 |
| 2 | 18 | − .0028 |
| 3 | 10 | − .0026 |
| 4 | 6 | −0.0025 |
| | 47 | −0.0026 A |

Professor Julius adds: "If, however, the accuracy attained would permit of regarding such deviations as genuine, the interpretation of the displacements on the basis of the Doppler effect

[1] Kayser, *Handbuch der Spectroscopie*, **6**, 864, 1912.

would be condemned. One could not reasonably admit the various absorption centers present in a gas-current at a certain level to have different proper velocities of outflow from the spot vortex."[1]

It was precisely because the deviations were considered to be genuine and because one could not reasonably admit that the absorption centers present in a gas-current at a certain level can have different velocities, that one was led to the assumption that they are at levels differing with their velocities. It is to be observed that the deviations between the displacements of the lines of these elements and of iron are of the same order as those between iron lines of neighboring intensities which Professor Julius considers to be genuine and explicable from the point of view of his theory.

In saying that the displacements of the Fe lines of intensity 4, for example, are in magnitude between those for lines of intensities 3 and 5, it is meant that, when the data are sufficient, the mean displacement for lines of intensity 4 is less than that for lines of intensity 3 and more than that for lines of intensity 5; not that the statement is true for every line of the respective intensities, otherwise there would be no room for errors of measurement and no need for the tedious duplication of observations by extending them to ever-larger numbers of lines. In an exactly similar way and to the same degree, one is justified in saying that the displacements of the lines of the heavy elements are, as a class, greater than for the iron lines of corresponding intensities. There are several grounds for expecting deviations from the mean: (1) errors of measurement of weak lines which are inherently great are somewhat above normal because in general the intensity of development of the plates was intended for the measurement of lines of medium intensities; (2) errors in the Rowland intensities, which are quite large for the weaker lines, in which case the individual variations are so pronounced that the results for a single line must be accepted with caution unless its intensity is verified; (3) there is always the possibility of the line in question being an undetected blend, especially in the ultra-violet region where the lines are so numerous; (4) there are apparently differences characteristic of the different

[1] *Astrophysical Journal*, **40**, 7, 1914.

groups of lines of a given element.[1] It is first necessary, however, to establish the broader outlines of a general truth, if it exists, then later the individual variations may be used to push investigation a step farther.

## GENERAL DISPLACEMENTS OF FRAUNHOFER LINES

Another deduction from the dispersion theory is said by Professor Julius to be proved by the center and limb displacements observed by Adams. These displacements, according to that theory, are a more pronounced effect of the general shifting of the Fraunhofer lines to the red, which is ascribed to their asymmetry. Both phenomena, the general shift and the center and limb effect, are similarly produced, are subject to the same laws, and may be judged by the same criterion. In the case of the center and limb observations the displacements are small for lines of weak intensity, increase to a maximum for lines of intermediate intensity, then decrease for lines of great intensity. Professor Julius says: "This is exactly what our theory requires. . . . . Lines of moderate intensity should show the largest displacements, as they really do."[2]

It is interesting to compare the above definite statement with the results obtained from observations of general shift. The Fe lines of the groups *a*, *b*, and *c*4 are the best lines in the iron spectrum for standards, their wave-lengths, under constant pressure, are independent of arc conditions, and the lines are of excellent quality both in the arc and in the solar spectrum. An extended series of observations on sun-arc displacements is a part of the Mount Wilson program. Some preliminary results are now being prepared for publication and their general discussion will appear later. In the list are 105 lines of groups *a*, *b*, and *c*4. A synopsis of the means taken by intensities is given in Table XIII.

For comparison the limb-center shifts are included, and also the sun-arc results of Evershed. The result based upon these lines for which sun-arc displacements can be obtained with high precision is at variance with the deduction from the anomalous dispersion

[1] *Mt. Wilson Contr.*, No. 74; *Astrophysical Journal*, **38**, 352, 1913.

[2] *Observatory*, **37**, 256, 1914.

theory. For lines of moderate intensity 5 the displacement is a minimum instead of a maximum. The march of the phenomenon for the iron lines shown by Fig. 2 appears not to be accidental, for the lines of group *a* taken separately, the two sections of the *b* lines in the violet and red respectively, and the lines of the same groups in the list published by Evershed[1] show a similar march of displacement with intensity.

TABLE XIII

SUN-ARC DISPLACEMENTS—IRON LINES

| | Intensity | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 10–15 |
| No. of lines | 9 | 22 | 29 | 16 | 13 | 5 | 10 | 3 |
| Sun-arc... | +0.0047 | +0.0038 | +0.0030 | +0.0020 | +0.0042 | +0.0058 | +0.0090 | +0.0110 |
| Evershed.. | + .0083 | + .0047 | + .006 | + .0055 | + .0077 | + .0135 | + .0134 | + .015 |
| Limb-center... | +0.0066 | +0.0068 | +0.0071 | +0.0088 | +0.0083 | +0.0088 | +0.0079 | +0.0041 |

There are many lines showing negative shifts for the sun-arc comparison. The evidence that these displacements to shorter wave-length are real will be found in the paper to which reference is made above. Shifts in the solar atmosphere to shorter wave-lengths appear to be unaccounted for by the anomalous dispersion theory.

A further and very serious difficulty for the theory appears in classifying the lines into groups by sun-arc displacements, that is, in putting into each category lines showing similar behavior in the sun, as the lines fall into the same groups as when classified by pressure-shift in the laboratory. The hallmark of pressure-shift is evident, but discussion is reserved for the paper on "Pressures in the Solar Atmosphere" now in preparation. It is of interest here only from its bearing upon the deduction from the anomalous dispersion theory.

In reference to the limb-center displacements Professor Julius remarks: "Adams himself considers pressure as the effective agent

[1] *Kodaikanal Observatory Bulletin*, No. 36, 1913.

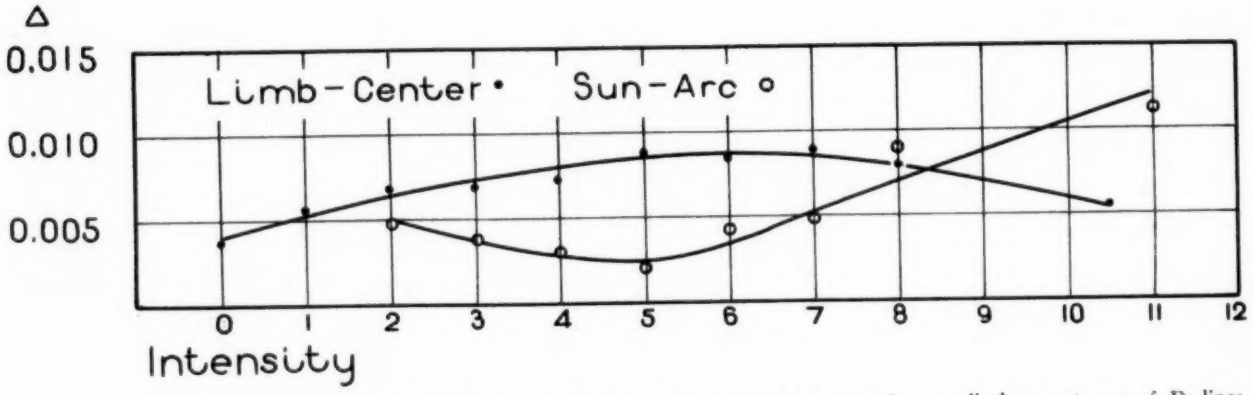


FIG. 2.—Limb-center displacements are from the observations of Adams. Sun-arc displacements are of Fe lines of groups *a*, *b*, *c*4.

in producing these displacements; it therefore did not occur to him to classify the shifts according to line intensity."[1]

It would more accurately represent Mr. Adams' attitude to say that he did not classify the shifts according to line intensity because he recognized that the characteristic behavior of the elements and classes of lines would be concealed rather than revealed by the treatment of heterogeneous data *en masse*. It seems to be implied that Mr. Adams considered pressure the only effective agent concerned in the center and limb displacements. Such an inference is hardly consonant with Mr. Adams' discussion of the question of the heavy elements and the enhancement of lines, and his treatment of scattering, motion, and level. In respect to the latter he begins a discussion with the expression: "Since the matter of level appears to be the most significant factor in determining the amount of the displacement for any given line . . . . ;[2] and it was at his suggestion that I took up the question of level and center-limb displacements in my second paper on "Radial Motion in Sun-Spots."[3]

## ERRORS OF OBSERVATION

Professor Julius says: "A very marked fact not explained by St. John's theory, viz., the large deviation of individual displacements from the means for each intensity class and spectral region, is shown to be in harmony with our interpretation on the basis of anomalous dispersion."[4]

There are 131 lines in the lists of those to the violet or red of stronger lines. In such cases the large deviations explained only by the dispersion theory should be in evidence. The mean deviation for these lines without regard to sign is 0.003 A, which compares favorably with the precision obtainable in other solar spectrum measurement where the difficulties of measurement are of the same order. The mean of the 25 largest deviations of this class is 0.007 A, while for 25 lines not under the influence of stronger lines it is 0.009 A.

[1] *Astrophysical Journal*, **40**, 27, 1914.

[2] *Mt. Wilson Contr.*, No. 43, p. 26; *Astrophysical Journal*, **31**, 55, 1910.

[3] *Mt. Wilson Contr.*, No. 74, p. 23; *Astrophysical Journal*, **38**, 341, 1913.

[4] *Astrophysical Journal*, **40**, 25, 1914.

As to the lack of proportionality between displacements and wave-lengths, Professor Julius says: "One cannot admit such fluctuations to be entirely accidental or due to observational errors. The important retrograde differences between the values for the mean λ 4732 and mean λ 5235, e.g., far exceeds the mean errors of the result of 76 and 86 observations, and must be genuine."[1]

On this point I am unable to make so definite a statement. I can only say I was impressed by the great difference in absolute values obtained from exposures taken in immediate succession even upon the same plate and in the same region. The area of maximum displacement is very narrowly localized at the edge of the penumbra, and unless the seeing is exceedingly fine the slit cannot be placed on the exact point; and when, as was sometimes the case, observations had to be made under conditions of poor seeing when the edge of the penumbra nearly disappeared, still greater variations were found. Although Professor Julius considers the high values of the displacements in the region λ 4634–λ 4829 to represent a genuine divergence, he has nevertheless treated them as accidental in determining his normal displacements by a smoothing-out process. Consequently the normals are high for the violet and green regions and low for the region of mean λ 4732. In selecting the six spectral regions there was no thought of using them for determining the relation between displacement and wave-length. It was plain that an impracticable number of observations for each region would be required to eliminate the accidental differences between the regions. When, however, the results were finally assembled, the variation of displacement with wave-length was so evident, in spite of the deviations for the separate regions, which my experience told me might be due to observational conditions, that it seemed a fair assumption to refer these displacements to the Doppler effect and to leave final appeal to observation until the approaching spot maximum.

In considering the data in my original list of displacements, a clear distinction should be kept in mind between errors of measurement and errors of observation. In any one of the six spectral regions the relative displacements of the different lines are subject

[1] *Ibid.*, **40**, 24, 1914.

only to errors of measurement, while the relative values for the means of the segregated regions are affected by the large variations in absolute displacements from plate to plate inherent in the difficulties of the observations.

## SOME OUTSTANDING DIFFICULTIES

1. The regular progression of the heights given by flash spectrum lines with solar intensities leads directly to the same relative levels as those deduced from the displacements in the penumbrae of spots. The explanation on the theory of anomalous dispersion would seem to require anomalous dispersion to be directly proportional to the intensities of lines, and the arcs given by flash lines to be directly proportional to the anomalous dispersion of the lines, neither of which appears to be in harmony with observation.

The 346 Fe lines, unenhanced and identified only with iron, in Mitchell's Table I, show the following results:

| | No. of Lines | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | 19 | 30 | 55 | 72 | 49 | 40 | 28 | 24 | 25 |
| Solar intensities | ∞ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7–8–9 | 10–40 |
| Heights in km | 275 | 279 | 288 | 344 | 369 | 397 | 425 | 488 | 590 | 806 |

2. The regular change in the intensities in the flash lines relative to the intensities of the corresponding solar lines is a marked phenomenon and is not an obvious deduction from the anomalous dispersion theory. There are in Mitchell's Table I, 1181 unenhanced lines of intensity 6 or less assigned to single elements. The differences, flash−solar intensity, expressed in intensity intervals, are as follows:

| | No. of Lines | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 18 | 69 | 164 | 166 | 189 | 185 | 166 | 109 | 71 | 44 |
| Solar intensity | ∞∞∞∞ | ∞∞∞ | ∞∞ | ∞ | 1 | 2 | 3 | 4 | 5 | 6 |
| Flash−solar | +3.4 | +2.3 | +1.4 | +0.6 | +0.1 | −0.7 | −1.1 | −2.1 | −2.7 | −3.2 |

3. Some two years ago I published observations showing displacements when the slit of the spectrograph is perpendicular to the

radius of the solar disk passing through the center of the umbra.[1] It is implied by Professor Julius that such displacements are only occasional and occur when the region of minimum density has not a symmetrical shape.[2] Of the spots examined at the time of publication, 70 per cent showed such displacements and practically all spots examined since then by more refined methods of observation have shown these displacements. They occur and persist for weeks in regular and symmetrical spots, so that one can hardly admit that "there is no difficulty in accounting for the occasional displacements in question on the basis of unequal refraction at opposite edges of the spots." It may be possible to imagine a density distribution capable of producing the effect "since almost any peculiarity in the appearance of spectral lines may be explained by anomalous dispersion, if only we are at liberty to assume the required density distribution,"[3] but that such an artificial condition characterizes a regular spot during at least the greater part of its life seems improbable, and the mind reverts to the obvious explanation based on vortex motion.

4. There are some lines displaced in the opposite direction in the penumbrae of spots, but their small number does not lessen the difficulty for the dispersion theory. Not only are they among the most important chromospheric lines, but they often show displacements that are pronounced and obvious without measurement, they appear in every observation, and indicate a comparatively stable condition during the life of a spot. Up to the present the anomalous dispersion theory has been unable to suggest an explanation, and the Doppler effect due to the inflow of the upper chromospheric vapors is as yet the only one proposed.

5. No explanation is furnished by the dispersion theory of the differences characteristic of the elements such as those shown by the displacements of the lines of iron, titanium, and the heavy elements when lines of the same region and intensity are compared.

## EFFECTIVE LEVELS

The idea of levels has been employed in all spectroheliographic work, particularly by Hale and Deslandres, and has been previously

[1] *Mt. Wilson Contr.*, No. 54, p. 20; *Astrophysical Journal*, **34**, 76, 1911.

[2] *Ibid.*, **40**, 29, 1914. [3] *Ibid.*, **25**, 111, 1907.

discussed by Abbot[1] and by the writer.[2] It is a familiar observation that the different arc lines of iron, for example, are not produced with equal relative intensity in all parts of the arc. Some appear only at the poles, others only in the core, while others are characteristic of the flame of the arc. For these three classes of lines the effective centers of radiation are not uniformly distributed throughout the mass of radiating vapor. If such a body of vapor were backed by a suitable continuous spectrum, the absorption lines would be referable to different portions of the arc. Suppose, for example, that the core of the arc could be put into rotation with a velocity greatly differing from that of the outer layers. Such a difference in motion could conceivably be detected by the inclination of the spectrum lines if the slit of the spectrograph were normal to the axis of the arc, since different portions of the arc are effective in the production of the classes of lines considered. Again let us consider systems of electrons emitting a number of lines of very different intensities in a mass of vapor of solar proportions with a similar distribution of temperature and density. For the strongest lines the absorption coefficient is the greatest and there will be a spherical core from which no light of these wave-lengths reaches the surface, that is, the emergent light of these wave-lengths comes from a spherical shell. The total radiation is an integrated effect and its center of gravity locates the effective radius of the shell or the effective layer. From the levels of the shorter radii of the shell the light emitted at the outer surface is small owing to the absorption; from the levels of the longer radii it is again small owing to the lower temperature; it is evident that the really effective level lies between these extremes. The lines will appear dark, as Abbot suggests, in contrast to the light that is not selectively absorbed, since such radiation comes from lower and hence hotter levels. If attention be directed to the weakest lines of the system, it is seen that light of these wave-lengths will reach the surface from a greater depth owing to the smaller coefficient of absorption, that low levels will be more effective and the higher

[1] *The Sun*, pp. 97 and 251.

[2] *Mt. Wilson Contr.*, No. 74, p. 5; *Astrophysical Journal*, **38**, 345, 1913; *Mt. Wilson Contr.*, No. 88, p. 18; *Astrophysical Journal*, **40**, 373, 1914.

levels less effective for the weakest than for the strongest lines, so that the center of gravity of the integrated effect is lower, that is, the effective level is lower for the weakest lines than for the strongest lines. From this point of view it is evident that the existence of tangential velocities varying with the depth could be detected spectroscopically. That these lines of different intensities may belong to a series does not seem to require modification of the discussion.

Professor Julius urges against this point of view that in the laboratory a gas such as $NO_2$ shows at the same time strong and weak lines. It is also true that the calcium spark gives ordinarily $\lambda$ 4226.9, H, K, and many weaker lines, but de Gramont[1] has shown that K is the ultimate line, the last to disappear when the quantity of the element tends toward zero. If the quantity be sufficient to show K only, it is evident that the corresponding absorption spectrum would show K only, and that with increasing quantities of Ca vapor H, $\lambda$ 4226.9, and other lines would appear in succession. It seems a clear deduction that the upper portion of the Ca envelope of the sun would be the source of the $K_3$ line and that a greater depth of vapor would be necessary to produce the line $\lambda$ 4226.9, or the center of gravity of its effective layer would be lower. In the laboratory experiment with $NO_2$ the range of intensity of the absorption lines depends upon the quantity of vapor in an apparently similar way.

## SUMMARY

1. In the lists published by Professor Julius there are 43 lines to the violet and 39 lines to the red of stronger lines. Among the 506 lines of my original list there are 24 other lines to the violet and 25 to the red of stronger lines within half an angstrom of stronger lines. Using the Julius normals the mean residual for the additional lines to the violet is +0.0023 A, and for those to the red −0.0034 A, results opposite to those given by the lines selected by him, and at variance with the theory.

2. In deducing the normal displacements for a given intensity and region from those for the separate regions, one is dealing with non-homogeneous series of observations. The use of these normals

[1] *Comptes rendus*, **159**, 5–12, 1914.

introduces residuals that are systematically negative for lines in Professor Julius' lists which are to the violet of stronger ones, because such lines are all in the violet and green regions, for which the normals are too large. The apparent positive residual for lines to the red of stronger ones depends upon 7 lines in the blue series for which the normals are 0.009 A less than the mean for all lines of the same intensity and region.

3. Using as standard displacements in any homogeneous series the means from all lines of a given element and intensity in that region, the resulting residual for the 67 lines to the violet is −0.0003 A and for the 64 lines to the red −0.0004 A. For the 131 lines the sum of the favorable residuals is 0.212 A, of the unfavorable residuals 0.218 A. Tested, then, by standards deduced from the homogeneous group of observations to which they are to be applied, the lines in the near neighborhood of stronger lines show no systematic differences from lines not so situated.

4. Influencing lines showing very strong anomalous dispersion exert no greater effect upon neighboring lines than those showing very weak anomalous dispersion.

5. New measurements of weak lines in the broad shadings of the strongest lines in the solar spectrum show no systematic differences for lines near them nor any systematic progression in the displacements as the strong lines are approached.

6. Criteria given by Professor Julius relating anomalous dispersion to the chromospheric and limb spectra are applied with results unfavorable to the theory, and consideration is given to the increasing indefiniteness of the correlation between laboratory results on anomalous dispersion and solar observation.

7. Professor Julius compared the displacements of the lines of the heavy elements with the standard displacements of the iron scale, which are high for the violet region, and by this procedure reduced the positive residuals. The displacements of the 21 lines of the heavy metals exceed those for the same intensities of iron on the average by +0.003 A when comparison is made with iron lines upon the same plates.

8. The general displacements of the Fraunhofer lines to the red are a minimum for lines of medium intensities, a result opposite to

that required by the anomalous dispersion theory; and there are, moreover, many lines displaced to shorter wave-length, a phenomenon yet unaccounted for by the theory.

9. Classified by their displacements in the solar atmosphere the iron lines fall into the same classes as when classified by pressure-shift, a result apparently not to be explained by anomalous dispersion.

10. A consideration of errors shows that for a given region they are not abnormal for weak lines near stronger ones, and that the departures from regularity, when unconnected regions are compared, may be referred to the difficult observing conditions.

11. The general conclusion from this review of solar observations is that the deductions from the anomalous dispersion theory which are susceptible of definite and quantitative tests are not supported by the observational data, and that observations are outstanding which have not yet been explained by the theory.

MOUNT WILSON SOLAR OBSERVATORY
October 22, 1914

# *Minor Contributions and Notes*

## ON THE SPECTRUM OF YTTRIUM

In a preceding article[1] I have investigated briefly the spectrum of yttrium with regard to the arrangement of the strongest lines in groups with constant differences between their wave-numbers. In that work three constant differences were discovered with the values 205.00, 84.67, and 3241.48, respectively. The first of these occurs in the case of seven pairs of strong lines; the second in three. The third difference, which occurs in two pairs only, should, as I afterward found, be replaced by 143.84. The four lines which form the two pairs should be interchanged.

Since then I have made a more careful investigation of the same spectrum, the results of which are given in the following. The measurements of the wave-lengths, taken from Kayser, are the most exact, and reach from λ 6701 to λ 2227. Some lines, however, not being given by Kayser, but certainly existing, have also been included, for instance λ 4236.10. Its intensity, according to Exner and Haschek, is 10, while Eberhard calls it 6.

The above-mentioned difference 205.00 belongs to a group of 4 lines. Designating the wave-numbers of the first line (with the greatest wave-length) in each group by $A$, we get for the wave-numbers $B$, $C$, and $D$ of the other lines in the same group:

$$B = A + 1846.91$$
$$C = A + 2251.69$$
$$D = A + 2456.65$$

The differences between the lines in each group are in the mean 1846.91, 404.78, and 204.96, respectively.

I have brought together all the lines belonging to this group in Table I, which is arranged in the following manner. In the columns, called $A$, $B$, $C$, and $D$, are given the wave-numbers (in the calculation of which but two decimals have been used in the wave-length); in the columns I, $\Delta_1$, $\Delta_2$, and $\Delta_3$ are given the intensities

[1] *Beiträge zur Kenntnis der Linienspectren.* Diss. Lund, 1914; *Annalen der Physik.*, **45**, 429, 1914.

of the lines, according to Exner and Haschek, and the differences of their wave-numbers.

TABLE I

| $I$ | $A$ | $\Delta_1 = 1846.91$ | $I$ | $B = A + 1846.91$ | $\Delta_2 = 404.78$ | $I$ | $C = A + 2251.69$ | $\Delta_3 = 204.96$ | $I$ | $D = A + 2456.65$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 15633.33 | 1846.74 | 4 | 17480.07 | 405.28 | 1 | 17885.35 | 205.13 | 10 | 18090.48 |
| 10 | 16069.96 | 1847.01 | 1 | 17916.97 | ..... | ... | ..... | ..... | ... | ..... |
| ... | ..... | ..... | ... | ..... | ..... | 1* | 16439.80 | 204.87 | 2 | 16644.67 |
| ... | ..... | ..... | 2 | 17006.16 | 404.62 | 1* | 17410.78 | ..... | ... | ..... |
| ... | ..... | ..... | 1 | 17420.33 | ..... | ... | ..... | (609.93) | 3 | 18030.26 |
| ... | ..... | ..... | ... | ..... | ..... | 1† | 17618.50 | 204.96 | 1 | 17823.46 |
| 2 | 19243.39 | 1846.54 | 4 | 21089.93 | 404.76 | 2 | 21494.69 | ..... | ... | ..... |
| 10 | 19655.63 | (2252.19) | ... | ..... | ..... | 2 | 21907.82 | 205.11 | 2 | 22112.93 |
| 1 | 20207.17 | 1846.95 | 2 | 22054.12 | ..... | ... | ..... | ..... | ... | ..... |
| 1 | 20344.89 | 1847.05 | 8 | 22191.94 | ..... | ... | ..... | (609.70) | 2 | 22801.64 |
| ... | ..... | ..... | ... | ..... | ..... | 1 | 20357.82 | 204.85 | 2 | 20562.17 |
| ... | ..... | ..... | 10 | 20406.91 | 404.79 | 3 | 20811.70 | ..... | ... | ..... |
| 2 | 20484.96 | (2251.61) | ... | ..... | ..... | 10 | 22736.57 | 205.00 | 8 | 22941.57 |
| 4 | 21356.11 | 1846.93 | 20 | 23203.04 | 404.97 | 10 | 23608.01 | 204.69 | 3 | 23812.70 |
| ... | ..... | ..... | 4 | 21715.62 | ..... | ... | ..... | (609.89) | 2 | 22325.51 |
| ... | ..... | ..... | 2 | 21732.14 | ..... | ... | ..... | (609.74) | 4 | 22341.88 |
| ... | ..... | ..... | ... | ..... | ..... | 4 | 22283.23 | 204.80 | 4 | 22488.03 |
| ... | ..... | ..... | 1 | 22557.32 | ..... | ... | ..... | (609.75) | 2 | 23167.07 |
| ... | ..... | ..... | 3 | 22753.95 | 404.65 | 1* | 23158.60 | ..... | ... | ..... |
| 50 | 22856.57 | 1846.99 | 8 | 24703.56 | 404.71 | 20 | 25108.27 | 204.98 | 20 | 25313.25 |
| 15 | 23936.73 | 1846.97 | 2 | 25783.70 | 404.52 | 5 | 26188.22 | 205.08 | 20 | 26393.30 |
| 5 | 24241.95 | 1847.21 | 10 | 26089.16 | 404.49 | 20 | 26493.65 | ..... | ... | ..... |
| 3 | 25305.30 | 1846.55 | 1 | 27151.85 | 405.09 | 10 | 27556.94 | 204.87 | 10 | 27761.81 |
| 3 | 25440.11 | 1846.95 | 20 | 27287.06 | 404.64 | 20 | 27691.70 | 204.95 | 10 | 27896.65 |
| ... | ..... | ..... | ... | ..... | ..... | 5‡ | 26478.00 | 205.03 | 5 | 26683.03 |
| ... | ..... | ..... | ... | ..... | ..... | 2 | 26846.22 | 204.78 | 2 | 27051.00 |
| ... | ..... | ..... | 20 | 27770.99 | 404.77 | 10 | 28175.76 | ..... | ... | ..... |
| 3‡ | 27871.53 | 1846.86 | 3 | 29718.39 | ..... | ... | ..... | ..... | ... | ..... |
| 1† | 28630.98 | 1846.97 | 3 | 30477.95 | ..... | ... | ..... | ..... | ... | ..... |
| 5 | 28994.25 | 1847.00 | 20 | 30841.25 | 404.94 | 10 | 31246.19 | 204.90 | 5 | 31451.09 |
| 3 | 28834.81 | [2251.88] | ... | ..... | ..... | 20 | 31086.69 | 204.97 | 10 | 31291.66 |
| 20 | 30047.99 | 1846.98 | 4 | 31894.97 | 404.77 | 8 | 32299.74 | ..... | ... | ..... |
| ... | ..... | ..... | 1* | 33219.72 | 404.58 | 1 | 33624.30 | 205.20 | 1 | 33829.50 |
| ... | ..... | ..... | 1† | 35498.00 | 404.90 | 1 | 35902.90 | ..... | ... | ..... |
| ... | ..... | ..... | ... | ..... | ..... | 1 | 43903.17 | 205.06 | 1 | 44108.23 |
| ... | ..... | ..... | ... | ..... | ..... | ... | ..... | ..... | ... | ..... |
| ... | ..... | ..... | ... | ..... | ..... | ... | ..... | ..... | ... | ..... |
| ... | ..... | ..... | ... | ..... | ..... | ... | ..... | ..... | ... | ..... |

* Seen by Kayser only. † Seen by Exner and Haschek only. ‡ Not seen by Kayser.

All places are not occupied by lines in Table I. In some cases the gaps may be caused by lines unobserved on account of their small intensities. In other cases this is not to be assumed, for the

remaining lines of the same row have too great intensity and a gap here must depend upon unknown causes.

The lines, the wave-numbers of which have the differences 143.84 and 84.93, seem to be isolated pairs in the spectrum and I have not been able to find any corresponding lines. The pairs with these two differences are given in Tables II and III. The

TABLE II

| *I* | *A* | $\Delta = 143.84$ | *I* | *B* |
|---|---|---|---|---|
| 1* | 16257.68 | 143.83 | 1* | 16401.51 |
| 3 | 20747.49 | 143.51 | 3 | 20891.00 |
| 8 | 18148.42 | 144.25 | 10 | 18292.67 |
| 2 | 20492.51 | 143.66 | 8 | 20636.17 |
| 5 | 21003.24 | 144.17 | 5 | 21147.41 |
| 3 | 21322.24 | 143.99 | 8 | 21466.23 |
| 10 | 21390.23 | 143.58 | 10 | 21533.81 |
| 1* | 21610.45 | 143.96 | 6 | 21754.41 |
| 1 | 21807.82 | 143.72 | 3r | 21951.54 |
| 2 | 22154.48 | 143.95 | 2 | 22298.43 |
| 3 | 22351.01 | 143.69 | 3 | 22494.70 |
| 3 | 22503.11 | 144.12 | 2 | 22647.23 |
| 1* | 22759.39 | 143.82 | 4 | 22903.21 |
| 2† | 28314.09 | 143.67 | 2† | 28457.76 |
| 1 | 32786.68 | 143.69 | 2 | 32930.37 |
| 1 | 44016.99 | 143.84 | 2 | 44160.83 |

*Seen by Kayser only. † Seen by Exner and Haschek only.

TABLE III

| *I* | *A* | $\Delta = 84.93$ | *I* | *B* |
|---|---|---|---|---|
| 3 | 15119.46 | 84.81 | 1 | 15204.27 |
| 10 | 17658.01 | 85.17 | 1* | 17743.18 |
| 1* | 17675.71 | 85.17 | 8 | 17760.88 |
| 3 | 17959.87 | 84.64 | 2 | 18044.51 |
| 8 | 20576.00 | 84.94 | 10 | 20660.94 |
| 4 | 22789.90 | 84.92 | 1 | 22874.82 |
| 2 | 23303.39 | 84.86 | 1 | 23388.25 |
| 10 | 23522.00 | 84.62 | 10† | 23606.62 |
| 20 | 24136.98 | 85.07 | 30 | 24222.05 |
| 1* | 24416.33 | 85.13 | 3 | 24501.46 |
| 10 | 28602.23 | 84.85 | 5 | 28687.08 |

*Seen by Kayser only. † Not seen by Kayser.

whole number of lines examined amounts to about 600. Of these, 146 occur in the tables above, and among them most all the strong

lines in the spectrum. It is very possible that more groups of lines can be obtained by further investigation.

EMIL PAULSON

KÅGERÖD
August 1914

## NOTE ON THE BLUE SPECTRUM OF ARGON

As is well known, the gas of argon possesses two quite different spectra, the red and the blue. Both spectra can be obtained in Geissler tubes under various conditions. As the quantity of electric energy transmitted to every molecule increases, the red spectrum gradually goes over into a mixed one and this at last into the so-called blue spectrum, which has but a few lines in common with the red spectrum.

The red spectrum of argon has already been examined by Rydberg,[1] who has shown that most of the lines for the interval λ 4702 to λ 2967 can be arranged in quadruplets. Afterward I made an investigation of the red and infra-red part of the spectrum,[2] which has established that the same quadruplet occurs here also. Designating the wave-number of the first line of each quadruplet by $A$, and those of the following by $B$, $C$, and $D$, we may write:

$$B = A + 846.47 \qquad \Delta_1 = 846.47$$
$$C = A + 1649.48 \qquad \Delta_2 = 803.21$$
$$D = A + 2256.71 \qquad \Delta_3 = 607.03$$

$\Delta_1$, $\Delta_2$, and $\Delta_3$ being the succeeding differences between the four lines of the quadruplet.

In order to ascertain whether relations were to be found between the two spectra, I examined all the lines measured by Kayser from λ 5145 to λ 2762. Although I expended a great deal of labor on it, the results of this examination were very insufficient. A group of four lines, however, was discovered, but it does not seem possible

[1] "On the Constitution of the Red Spectrum of Argon," *Astrophysical Journal*, **6**, 338, 1897.

[2] "Zur Kenntnis des roten Argonspektrums," *Physikalische Zeitschrift*, **15**, 831, 1914.

TABLE I

| $I$ | $A$ | $\Delta_1=844.49$ | $I$ | $B=A+844.49$ | $\Delta_2=1611.33$ | $I$ | $C=A+2455.82$ | $\Delta_3=149.55$ | $I$ | $D=A+2605.37$ | $\Delta_4=153.97$ | $I$ | $E=A+2759.34$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 19962.37 | 844.21 | 6 | 20806.58 | 1611.52 | 2 | 22418.10 | 149.27 | 4 | 22567.37 | 153.93 | 5 | 22721.30 |
| 1 | 20269.98 | 844.59 | 5 | 21114.57 | 1611.30 | 3 | 22725.87 | 149.55 | 4 | 22875.42 | | | |
| ... | ..... | ..... | 10 | 22997.90 | ..... | ... | ..... | (1760.91) | 2 | 24758.81 | 153.99 | 6 | 24912.80 |
| 9 | 22592.91 | 844.50 | 6 | 23437.41 | 1611.46 | 2 | 25048.87 | 149.60 | 4 | 25198.47 | 153.87 | 4 | 25352.34 |
| 6 | 23087.47 | 844.54 | 1 | 23932.01 | 1611.22 | 3 | 25543.23 | 149.66 | 4 | 25692.89 | | | |
| 5 | 23050.11 | 844.47 | 2 | 24494.58 | 1611.10 | 1 | 26105.68 | 149.68 | 1 | 26255.36 | 154.00 | 2 | 26409.36 |
| 1 | 24313.64 | 844.50 | 1 | 25158.14 | 1611.74 | 1 | 26769.88 | ..... | ... | ..... | ..... | ... | ..... |
| ... | ..... | ..... | ... | ..... | ..... | ... | ..... | (1760.63) | 2 | 27764.82 | 154.08 | 4 | 27918.90 |
| 2 | 25159.46 | 844.73 | 1 | 26004.19 | ..... | ... | ..... | ..... | ... | ..... | ..... | ... | ..... |
| 8 | 25969.20 | 844.40 | 9 | 26813.60 | 1611.00 | 1 | 28424.60 | ..... | ... | ..... | ..... | ... | ..... |

to find any relation between this group and the quadruplet in the red spectrum. The first two differences have nearly the same value, 846.47 and 844.48 respectively, but such a similarity, probably, is quite accidental.

However that may be, there is obviously reason for publishing the results of the research, although they at present cannot give an answer to the question of whether a certain connection exists between the two spectra. With the same notation as above, the group discovered may be represented by the following expressions:

$$\begin{aligned} B &= A + 844.49 & \Delta_1 &= 844.49 \\ C &= A + 2455.82 & \Delta_2 &= 1611.33 \\ D &= A + 2605.37 & \Delta_3 &= 149.55 \\ E &= A + 2759.34 & \Delta_4 &= 153.97 \end{aligned}$$

In Table I some wave-numbers of lines belonging to this group are inserted. The intensities of the lines are indicated by $I$. In the columns headed $A$, $B$, etc., and $\Delta_1$, $\Delta_2$, etc., are given the wave-numbers and their differences.

It will be remarked moreover, that there are a great many pairs in the spectrum, having the differences $\Delta_1$, $\Delta_2$, $\Delta_3$, and $\Delta_4$ and $C-A$, $D-A$, etc. The majority of these pairs surely also belong to the system. All these, however, have been omitted, in order to make the table shorter.

EMIL PAULSON

LUND
December 1914

## ON A DEVICE FOR AVOIDING SYSTEMATIC ERROR DEPENDING ON MAGNITUDE IN THE MEASUREMENT OF STELLAR PHOTOGRAPHS

In the wholesale determination of parallax and proper motion by means of photography there is no source of error nearly so troublesome as that depending on magnitude. I even think that but for this one error it would be already possible to free our results completely from systematic error, at least in the averages. I mean that if this error could be removed, there would seem to be no reason why we should not be able—in the average of a sufficient

number of observations or of a sufficient number of stars—to reach almost any desired accuracy. Meanwhile the removal of the error in question has always seemed to me of extraordinary difficulty. Notwithstanding all the thought which has no doubt been devoted to it by different astronomers, myself among the number, no really satisfactory way out of the difficulty has as yet been proposed, and personally I had almost given up the matter in despair when I was struck by the idea which lies at the basis of the method to be described. It seems to hold out good promise of a surprisingly simple and complete solution of the problem. Unfortunately I have not the means myself for thoroughly testing the method, and the first test, kindly made for me at the Potsdam observatory, promising though it appears, cannot be considered as sufficient proof. I must leave it to the interested astronomers to ascertain definitively the practical efficiency of the method. It is evident that our aim will be reached if we succeed in obtaining stellar photographs on which the stars of all different degrees of brightness are represented by perfectly equal images. This can be achieved, at least approximately, in the following way.

*a*) Let the region of the sky to be investigated be photographed on a plate placed slightly within the principal focus of the telescope. On the developed negative all the stars will be represented by circles having the same diameter. The density of the images will be different, the densest ones of course belonging to the brightest stars.

*b*) Now let the finished negative—which we will call the screen-plate—be put back in the telescope in its former position, care being taken that the cones of light of the several stars shall meet the plate in exactly the same places as before; and let a second photograph—the main plate—be taken *in focus* (the focal setting being only slightly altered on account of the passage of the light through the plane-parallel screen-plate).

It is at once evident that the light of a ***bright*** star, before reaching the main plate, will be considerably weakened because it has passed through the dense extra-focal image on the screen-plate. The light of a *faint* star, on the contrary, will have to pass only a faint film-screen and will consequently be but little weakened.

Hence the light of the stars reaching the main plate will be brought nearer to equality by means of the screen-plate. The amount of the change will depend on the time of exposure and possibly some other circumstances. We will of course try to choose these in such a way that the best obtainable approximation to equality of all the images is secured.

The plate courteously taken for me at Potsdam, in the way described, shows the images of all the stars, from α Lyrae down to the stars of the 10th magnitude, nearly equal. Naturally, however, no special arrangements had been made in the plate-holder, and as a consequence the plate is not wholly satisfactory. In an extensive use of the method it will be necessary to take some precautions.

First, in order not to introduce appreciable distortion by the passing of the light through the screen-plate, it seems necessary to use plate glass. There is already some evidence tending to show that, at least in large-scale photographs, sensible error due to distortion by the passage of the light through the glass is not to be feared (e.g., Slocum's parallax plates taken through a filter; Schlesinger's photographs taken with the film turned away from the objective). A few further experiments made expressly for the purpose are desirable.

Second, great care has of course to be taken in order that no light of the stars shall reach the main plate without having passed through the corresponding extra-focal images. If, on the night in which the focal plate is obtained, we guide on the same star that was used for obtaining the extra-focal plate, all that is required is that the screen-plate can be inserted in the plate-holder absolutely in the same position in the two cases. Arrangements for the purpose seem easy of realization. We may further increase the security against error if, in taking the main plate, we put a circular diaphragm on the tube of the telescope.

In conclusion, I wish to remark that according to my experience images obtained through a blackened film, instead of being injured, are on the contrary usually rather superior to the ordinary images. The reduction of the images of the brighter stars must further greatly increase the accuracy of the measurement. It

seems probable, therefore, that the introduction of the screen-plate will rather diminish than increase the accidental errors. But even if it were not so, a slight sacrifice on the score of accidental error must almost seem a matter of indifference if we may thereby hope to realize freedom from systematic error.

J. C. KAPTEYN

December 1914.